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A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE OHIO RIVER. IV. A RESURVEY OF THE OHIO RIVER BETWEEN CINCINNATI, OHIO, AND LOUISVILLE, KENTUCKY, INCLUDING A DISCUSSION OF THE EFFECTS OF CANALIZATION AND CHANGES IN SANITARY CONDITIONS SINCE 1914-1916

H. R. Crohurst

Public Health Service
Washington, D. C.

May 1933

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May, 1933

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IV. A RESURVEY OF THE OHIO RIVER BETWEEN CINCINNATI, OHIO, AND LOUISVILLE, KY., INCLUDING A DISCUSSION OF THE EFFECTS OF CANALIZATION AND CHANGES IN SANITARY CONDITIONS SINCE 1914-1916

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PREPARED BY DIRECTION OF THE SURGEON GENERAL

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CONTENTS

Page
Introduction 1
Purpose of the 1914–1916 survey 1
Changes subsequent to the 1914–1916 survey 2
Purpose of the present survey 2
Presentation of the data 3
Acknowledgments 3
Section I. Ohio River channel in 1929–30; changes since 1914–1916 4
  General 4
    Section of the channel investigated 4
    Extent of the watershed above Louisville, Ky 4
    Tributary areas 4
  Changes since the 1914–1916 survey 6
    Differences in channel conditions 7
    Comparison of stream flows in 1914–1916 and 1929–30 7
    Increase in population 8
    Increase in sewage and industrial waste pollution 9
Section II. Sources of pollution 10
  Population estimates 10
    Increases in population above Cincinnati, 1915 to 1930 11
    Increases in population between Cincinnati and Louisville, 1915 to 1930 11
  Sewered population 12
    Estimated sewered population above Cincinnati 12
    Estimated sewered population, Cincinnati to Louisville 13
  Industrial waste pollution 13
Section III. Hydrometric studies 13
  Presentation of the data 14
  Discharge estimates 14
    Methods of compilation 14
    Summaries of discharge estimates 15
  Time of flow estimates 17
    Methods of compilation 17
    Summaries of estimated times of flow 18
Section IV. Collection and analysis of samples 19
  Sampling stations 19
    Location and description of sampling stations 19
  Collection of samples 20
    Frequency of sample collection 20
    Methods of sample collection 21
  Transportation of samples 21
  Laboratory procedures 21
    Routine chemical and bacteriological determinations 21
    Methods of chemical and bacteriological analysis 22
Section V Chemical analyses 22
  Basic tabulations of the chemical results 23
  Precision of the chemical results 31
    Sources of the errors in the chemical results 31

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Section V. Chemical analyses—Continued.
- Precision of the chemical results—Continued. Page
  - Estimation of standard deviation of differences, probable error of the differences of the monthly means, and probable error of the monthly mean 32
  - Derivation of the standard deviation of differences, probable error of differences in monthly means, and probable error of monthly means 35
  - Comparison between the precision of the 1929–30 and 1914–1916 results 36
- Discussion of the chemical determinations 38
  - Temperature 38
  - Hydrogen-ion concentration 39
  - Turbidity 39
  - Alkalinity 41
  - Oxygen relationships 43
  - Dissolved oxygen 44
  - Oxygen demand 49
  - Oxygen balance 58
  - Summary of the oxygen relationships 62
- Comparison between the 1914–1916 and 1929–1931 oxygen relationships below Cincinnati and Louisville 63

Section VI. Bacteriological studies 69
- Basic tabulations 69
- Bacterial pollution of the Ohio River 79
- Bacterial pollution of the Ohio River in the vicinity of waterworks intakes in 1914–1916 and 1929–30 81
- Relation of bacterial pollution to the contributing sewered population 85
- Comparison between the bacterial pollution of the Ohio River below Cincinnati and Louisville in 1914–1916 and 1929–1931 89
- Natural stream purification studies 95
  - Presentation of the data 95
  - Bacterial changes in 1929–30 96
  - Bacterial changes in 1914–1916 98
- Comparison of bacterial changes in 1914–1916 and 1929–30 102
- Bacterial pollution below Cincinnati in 1929–30, estimated from the 1914–1916 results, compared with the observed pollution in 1929–30 105

Section VII. General summary 107

LIST OF ILLUSTRATIONS

Diagram No. Page

1. Plan and profile of the Ohio River between Cincinnati and Louisville — 5
2. Changes in oxygen demand between stations 461 and 475, and corresponding changes in water temperatures and times of flow — 54
3. Changes in oxygen demand between stations 461 and 475 in relation to time and velocity of flow — 55
4. Changes in total equivalent sewered population, corresponding to changes in oxygen balance, between stations 461 and 475, with variations in velocity of flow — 59
5. Comparison between the rates of bacterial change below station 475 in 1929–1930, during a winter period of open channel and a summer period of pool stage — 97
6. Comparison between the seasonal rates of bacterial change below station 475 and below the point of maximum bacterial pollution in 1914–1916 — 101
7. Comparison between rates of bacterial change below station 475 in 1914–1916 and 1929–1930, during winter periods of open channel — 103
8. Comparison between the rates of bacterial change below station 475 in 1914–1916 and 1929–1930, during summer periods of pool stage — 104

LIST OF TABLES

No. Page

1. Location of cities, towns, bridges, dams, sampling stations, etc., on the Ohio River below sampling station 461, Cincinnati — 6
2. Run-off from the Ohio River watershed above the Great Miami River, expressed in inches of depth, by months, for the years designated — 8
3. Population as of April 1, 1930, above designated points on the Ohio River watershed — 10
4. Comparison of the 1915 estimated populations with those of 1930 on designated subdivisions of the Ohio River watershed — 11
5. Monthly average rates of discharge, in cubic feet per second, of the Little Miami, Licking, Great Miami, and Kentucky Rivers, at their mouths, November, 1929, to December, 1930 — 15
6. Average montly rates of discharge, in cubic feet per second, at designated points on the Ohio River between Cincinnati and Louisville, November, 1929, to December, 1930 — 16
7. Estimated mean monthly times of flow, in hours, between designated points on the Ohio River from Cincinnati to Louisville, November, 1929, to December, 1930 — 18
8. Cumulative mean monthly times of flow, in hours, through the Cincinnati metropolitan area, stations 461 to 475, and below the Cincinnati metropolitan area to Louisville, stations 475 to 598, November, 1929, to December, 1930 — 18
9. Summary of monthly average results of chemical analyses at each sampling station, arranged by months. Seasonal averages for each sampling station — 23

No. Page

10. Amounts of various chemical constituents, expressed as the daily average in pounds, carried by the Ohio River at station 492, compared with the sum of the amounts carried by the Great Miami River and the Ohio River at station 488 ... 33

11. Distribution of the deviations (d_4) of various constituents of Table No. 10 ... 35

12. Summary of the precision of various chemical determinations using data at sampling stations on the Ohio River above and below the Great Miami River ... 37

13. Average monthly and seasonal temperatures, degrees centigrade, arranged by sampling stations and months ... 39

14. Average monthly and seasonal turbidity, parts per million, arranged by sampling stations and months ... 40

15. Distribution of turbidities of individual samples from the Ohio, Little Miami, Licking, and Great Miami Rivers during periods of unobstructed flow ... 41

16. Average monthly and seasonal alkalinity, parts per million, arranged by sampling stations and months ... 42

17. Comparison between the concentration of alkalinity, parts per million, in the Ohio River at Cincinnati and Louisville, in 1914–1916 and 1929–30, with varying channel conditions ... 43

18. Average monthly and seasonal dissolved oxygen, parts per million, arranged by sampling stations and months ... 45

19. Average monthly changes in dissolved oxygen, between designated points on the Ohio River, expressed as the daily average, in pounds, and as the percentage change ... 46

20. Equivalent sewered populations corresponding to the mean monthly decreases in dissolved oxygen between stations 461 and 475 ... 49

21. Average monthly and seasonal oxygen demand, parts per million, at 20° C., arranged by sampling stations and months ... 50

22. Average monthly changes in oxygen demand, between designated points on the Ohio River, expressed as the daily average, in pounds, and as the percentage change ... 52

23. Changes in oxygen demand between stations 461 and 475, at Cincinnati, expressed as the daily average, in pounds, for the month, and the corresponding monthly averages of water temperature, and velocity and time of flow ... 54

24. Increases in oxygen demand between stations 461 and 475, expressed as the daily average, in pounds, corrected for river temperature, time of flow below sources of pollution, and sedimentation ... 56

25. Average monthly changes in oxygen balance, between designated points on the Ohio River, expressed as the daily average, in pounds, and as the percentage change ... 58

26. Changes in dissolved oxygen, oxygen demand, and oxygen balance, between stations 461 and 475, at Cincinnati, during the period of pool stage, April to December, 1930, inclusive, expressed as the daily average, in pounds, and as the equivalent sewered population ... 60

27. Estimated rates of reaeration between stations 461 and 475, expressed in terms of pounds per day per thousand square feet of water surface, calculated from the amount by which the oxygen balance during May to December, 1930, inclusive, varied from that of April, 1930 ... 61

28. Calculated rates of reaeration, pounds per day per thousand square feet of water surface, between designated points on the Ohio River below Cincinnati ... 61

No. Page
29. Comparison between the seasonal averages of dissolved oxygen and oxygen demand, expressed as the daily average, in pounds, at sampling stations in the vicinity of Cincinnati during 1914–1916 and 1929–30 64
30. Comparison between the seasonal averages of dissolved oxygen and oxygen demand, expressed as the daily average, in pounds, at sampling stations in the vicinity of Louisville, during 1914–1916 and 1929–1931 67
31. Summary of bacteriological observations by stations in terms of concentration and "quantity units" (bacteria per cubic centimeter × discharge in thousands of second-feet). Monthly means and seasonal averages at each station 71
32. Seasonal averages of bacteriological observations at each sampling station in terms of concentration and "quantity units" (bacteria per cubic centimeter × discharge in thousands of second-feet) 78
33. Yearly and seasonal averages of bacteria growing on agar at 37° C., at sampling stations on the Ohio River between Cincinnati and Louisville 79
34. Seasonal averages of quantity units of bacteria present in the Ohio River at sampling stations between the Little Miami and Kentucky Rivers 80
35. Comparison of monthly mean bacterial counts at station 461 (Cincinnati) and 598 (Louisville), during the years 1914–1916 and 1929–1931. Data arranged in order of magnitude of counts at station 461 with counts for correspondin[illegible]nth at Station 598 82
36. Average monthly and seasonal contributions of bacteria, in terms of quantity units and as the daily per capita contribution by the sewered population of the Cincinnati metropolitan area 86
37. Seasonal changes in the numbers of bacteria added to the Ohio River by the sewered population of Cincinnati 87
38. Average monthly and seasonal contributions of bacteria, in terms of quantity units, and as the daily per capita contribution by the sewered population of the Louisville metropolitan area 88
39. Seasonal changes in the numbers of bacteria added to the Ohio River by the sewered population of Louisville 89
40. Comparison of the bacterial pollution of the Ohio River below Cincinnati during 1914–1916 and 1929–30 90
41. Bacterial pollution of the Ohio River at Louisville in 1930–31, expressed as seasonal averages, in terms of quantity units 93
42. Bacterial pollution of the Ohio River at Louisville in 1914–15, expressed as seasonal averages, in terms of quantity units 94
43. Seasonal averages of quantity units of bacteria at sampling stations between Cincinnati and Louisville in 1929–30, corrected for tributary inflow and expressed as the percentage of those present at station 475, together with the times of flow from station 475 to successive points below 97
44. Seasonal averages of quantity units of bacteria at sampling stations between Cincinnati and Louisville in 1914–1916, corrected for tributary inflow and expressed as the percentage of those present at Station 475, together with the time of flow to successive points below 100
45. Comparison between the calculated and observed seasonal quantity units of bacteria in the Ohio River below Cincinnati, during 1929–30 106

A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE OHIO RIVER[1]

IV. A resurvey of the Ohio River between Cincinnati, Ohio, and Louisville, Ky., including a discussion of the effects of canalization and changes in sanitary conditions since 1914–1916

INTRODUCTION

Subsequent to the passage of an act of Congress, August 14, 1912, extending the scope of the Public Health Service to include, among other added duties, the study of "sanitation and sewage, including the pollution, either directly or indirectly, of navigable streams and lakes of the United States," the Public Health Service made an extensive study of the Ohio River during the period July, 1913, to December, 1916.

The purpose of this investigation was to obtain information which would serve:

(1) To give a quantitative statement of the pollution of the river in important zones, as existing at the time of the study, with such evaluation as possible of the relative importance of individual sources or units in contributing to this pollution, and the relation of the conditions to the public health.

(2) To furnish the basis for estimating, with reasonable precision, the changes in status of pollution which might be expected in the future to result from a given change in one or more of the factors concerned; as, for example, from a given increase in the various units of population, or from a given reduction in the polluting effect of their sewage by artificial treatment, or from changes in the velocity of flow due to the construction of additional dams for the improvement of navigation.

(3) To indicate the possibility of establishing definite quantitative relations between the intensity of pollution, as measured by various laboratory tests, and such obvious factors as were readily determinable by field surveys.

The report of this extensive investigation of the Ohio River was published in a series of Public Health Bulletins during 1923–1925, inclusive.[2]

At the time of this survey canalization of the main channel was in progress, 17 of the proposed 50 navigation dams having been placed in operation. Eleven of the completed dams were located within the first 75 miles below Pittsburgh, Pa., the other six at widely separated points along the remainder of the river. By 1930 canalization of the entire main channel had been completed, so that during periods of low water a series of pools could be formed between Pittsburgh and the Mississippi River to provide a 9-foot channel for the benefit of navigation.

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[1] Submitted for publication Aug. 16, 1932.

[2] A study of the pollution and natural purification of the Ohio River. Part I. The plankton and related organisms. By W. C. Purdy, Public Health Bulletin No. 131. Part II. Report on surveys and laboratory studies. By W. H. Frost, R. E. Tarbett, J. K. Hoskins, and H. W. Streeter, Public Health Bulletin No. 143. Part III. Factors concerned in the phenomena of oxidation and reaeration. By H. W. Streeter and E. B. Phelps, Public Health Bulletin No. 146.

In addition to changed channel conditions, a normal increase in population took place on the watershed between 1915 and 1930, together with changes in industrial activity, which resulted in increased sewage pollution of the river system and changes in the amount and character of industrial waste pollution.

Following complete canalization of the main channel it appeared desirable to make a resurvey of at least one section of the stream in order to ascertain in so far as possible:

(1) The extent to which the normal increase in population and changes in industrial activities during the intervening 15 years would be reflected by changes in the sanitary condition of the stream as indicated by differences in the chemical and bacteriological findings.

(2) The effects of canalization during periods of high water temperature and low stream discharge when the sewage and wastes flowed through a series of pools below the points of discharge.

(3) The present sanitary condition of the river, making possible a comparison of probable conditions in 1930 as forecast by the data collected in 1915, with conditions as they actually existed in 1930.

(4) Possible differences in the rates of chemical and bacteriological changes indicated by the two sets of observations as a result of changes in the amount and character of the pollution and in channel conditions.

In the latter part of 1929 it was possible for the United States Public Health Service to undertake a resurvey of a portion of the Ohio River as one of the major activities of its stream pollution investigations station located at Cincinnati, Ohio. This later survey at first covered the section between Cincinnati and the mouth of the Kentucky River, representing a river stretch approximately 82 miles in length. Chemical and bacteriological data were collected at regular sampling stations on this part of the river during the 14-month period November, 1929, to December, 1930, inclusive. In May, 1930, at the request of the Kentucky State Board of Health and the Sewerage Commission of the city of Louisville, the study was extended to include the Louisville area. Chemical and bacteriological samples were collected for a period of 13 months, May, 1930, to May, 1931, inclusive, at three sampling points in the immediate vicinity of Louisville. That the results from the two areas might be comparable, the Public Health Service maintained additional sampling stations on the Kentucky River and on the main stream below the mouth of this tributary during the 7-month period June to

December, 1930, inclusive. Therefore, for a period of seven months chemical and bacteriological data are available for a river section approximately 164 miles in length, extending from above Cincinnati to below Louisville.

In the accompanying report the data collected during the past and present investigations have been analyzed and compared under the following main divisions:

(I) General description of the main stream and its watershed between Cincinnati and Louisville, and changes since 1914–1916.

(II) The sources of pollution on the watershed, including population estimates, estimates of sewered population, and the effect of industrial wastes.

(III) The hydrometric studies, including rates of stream discharge and times of flow in the section of the river under observation.

(IV) The location of sampling points, method of sample collection and laboratory procedures.

(V) A discussion of the results of the chemical analyses.

(VI) The results and significance of the bacteriological findings.

(VII) General summary of findings.

It is desired to acknowledge the assistance rendered by the Kentucky State Board of Health, in furnishing laboratory space at Louisville for the analysis of samples collected in the vicinity of that city and for defraying the expenses of the analytical work at Louisville during the last five months of the investigation; and by the Sewerage Commission of Louisville in collecting and transporting all samples within the Louisville area throughout the entire investigation. Acknowledgment is also due the United States Army Engineer Corps and the United States Geological Survey, water resources branch, for supplying records of gage heights and estimates of stream flow on the main river and its tributaries between Cincinnati and Louisville, used in the hydrometric computations.

Individual acknowledgements are made to Mr. F. C. Dugan, director of the Bureau of Sanitary Engineering, Kentucky State Board of Health; to Mr. Woolsey M. Caye, technical engineer, Commissioners of Sewerage of Louisville; to Mr. C. T. Wright, technical assistant in sanitary engineering, United States Public Health Service, who has had general supervision of the field work throughout the section of the river under observation; and to the entire personnel of the stream pollution investigations station at Cincinnati, who have been freely called upon for, and have given valuable assistance throughout the investigation, and in the preparation of the final report.

Consultant W. H. Frost of the United States Public Health Service has been closely associated with the work, in a supervisory capacity, since its inception, and has rendered valuable assistance in criticizing the general outline of the proposed report and reviewing the final manuscript prior to its submission for publication.

SECTION I

OHIO RIVER CHANNEL IN 1929–30, CHANGES SINCE 1914–1916

GENERAL

The portion of the Ohio River to which the present investigation is confined consists of a section approximately 164 miles in length extending from Mile 461[3] located opposite the Cincinnati water works, near the upper limits of the metropolitan area, to Mile 624, opposite Kosmosdale, Ky., just above the Salt River and about 16 miles below the lower limits of the city of Louisville.

The area of the Ohio River watershed at the upper sampling station (Mile 461) which is just above the mouth of the Little Miami River, is 70,950 square miles, and above the Salt River, near the lower sampling point of the present survey, the area is 91,590 square miles. The section of the river under observation drains, therefore, approximately 20,600 square miles, or the equivalent of about one-tenth of the entire Ohio River watershed. Included within this area are the following main tributaries:

Tributary	Watershed
	Square miles
Little Miami River	1,714
Licking River	3,636
Great Miami River	5,411
Kentucky River	6,912
Combined area	17,673

The combined watershed area of these four main tributaries constitutes 86 per cent of the total drainage area between the upper and lower sampling stations. The remaining 14 per cent drains directly into the main stream or through minor tributaries.

Diagram No. 1 shows the main channel of the Ohio River between Cincinnati and Louisville and the location of dams, sampling stations and other points of importance. Included is a profile giving the elevation of water surfaces at pool stage. Table No. 1 indicates the distance, in miles, below sampling station 461, near the Cincinnati waterworks intake, to cities, towns, dams, sampling stations and other points on the river between Cincinnati and Louisville.

---

[3] All distances along the Ohio River are measured from the Point Bridge, Pittsburgh, the confluence of the Allegheny and Monongahela Rivers which form the Ohio River. Station numbers and other points of reference along the main river are designated in miles below Pittsburgh, so that differences in station numbers give approximate river distances. In the recently published charts of the Ohio River, issued by the U. S. Army Engineer Corps, distances below the Point Bridge are given along the river channel. In 1914–1916, distances below Pittsburgh were measured along a shore base line. The actual length of the Ohio River along the channel is 981 miles, as against the former figure of 966.5 by the base line measurement. Intermediate distances have of course been changed. In the present report, the original method of station and mile designation has been maintained, in order that the later chemical and bacteriological results, obtained at the same sampling points as in the previous investigation, may bear the same station number.

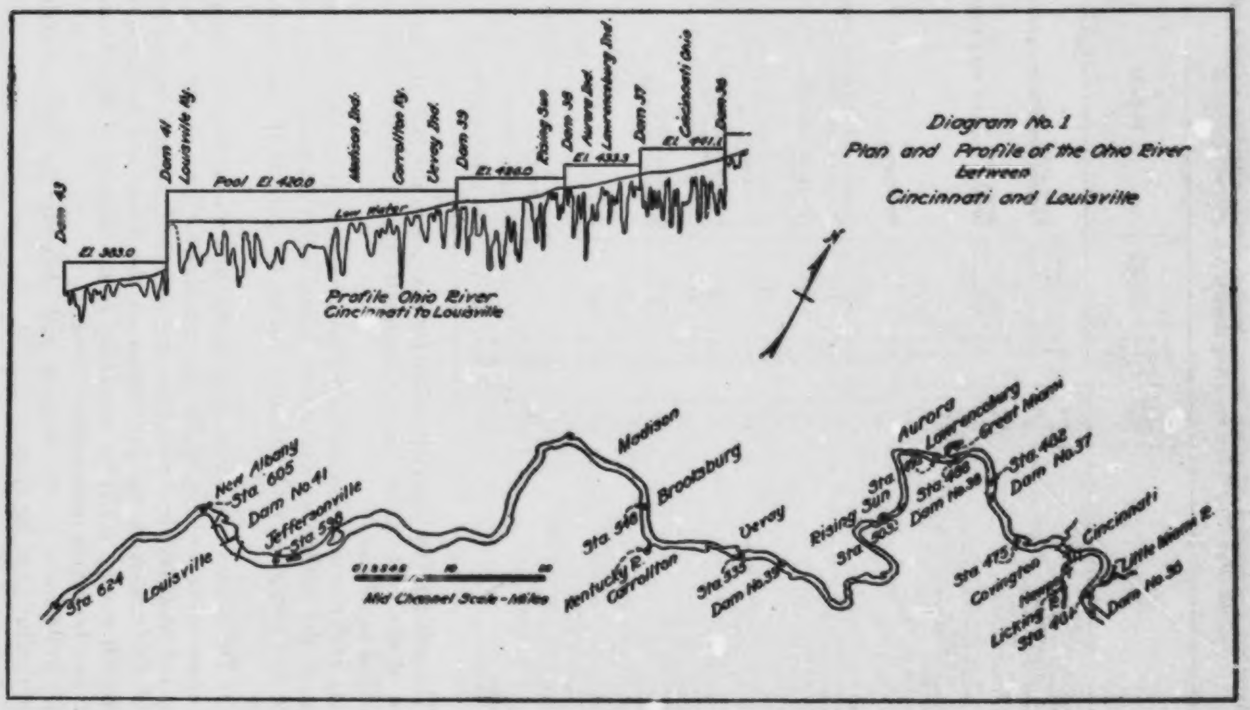

Diagram No. 1
Plan and Profile of the Ohio River
between
Cincinnati and Louisville

Dam 43
El 383.0
Dam 41
Louisville Ky.
Pool El 420.0
Madison Ind.
Carrollton Ky.
Vevay Ind.
Dam 39
El 430.0
Rising Sun
Dam 38
Aurora Ind.
Lawrenceburg Ind.
El 433.3
Dam 37
El 441.1
Cincinnati Ohio
Dam 36
Low Water
Profile Ohio River
Cincinnati to Louisville
N
New Albany
Sta 605
Dam No.41
Jeffersonville
Sta 598
Louisville
Sta 624
Mid Channel Scale - Miles
10
20
Madison
Brooksburg
Sta 546
Kentucky R.
Carrollton
Vevay
Sta 533
Dam No.39
Aurora
Lawrenceburg
Great Miami
Sta
Rising Sun
Sta 503
Sta 488
Dam No.38
Sta 482
Dam No.37
Sta 475
Covington
Newport
Licking R.
Sta 464
Cincinnati
Little Miami R.
Dam No.36

TABLE No. 1.—*Location of cities, towns, bridges, dams, sampling stations, etc., on the Ohio River below sampling station No. 461, at Cincinnati*

Name	Mile No.	Distance below mile 461.1	Side of channel	Remarks
Sampling station	461.1	0		
Cincinnati water works	461.4	0.3	Right	River gage.
Little Miami River	462.6	1.5	do	Drainage area 1,714 square miles.
L. & N. R. R. bridge	467.9	6.8		
Newport & Cincinnati bridge	468.2	7.1		
Public landing, Cincinnati	468.5	7.4	Right	Broadway gage.
Licking River	468.6	7.5	Left	Drainage area 3,636 square miles.
Suspension bridge	468.7	7.6		
C. & O. bridge	469.3	8.2		
Cincinnati-Southern R. R. bridge	470.7	9.6		
Mill Creek	470.8	9.7	Right	
Sampling station	475.0	13.9		
Ohio River Dam No. 37	481.3	20.2		River gages.
Sampling station	482.3	21.2		
Do	488.2	27.1		
Great Miami River	489.4	28.3	Right	Drainage area 5,410 square miles.
Lawrenceburg, Ind	491.1	30.0	do	Population 1930, 4,072.
Sampling station	492.2	31.1		
Aurora, Ind	494.8	33.7	Right	Population 1930, 4,386.
Ohio River Dam No. 38	501.3	40.2		River gages.
Sampling station	503.1	42.0		
Rising Sun, Ind	504.0	42.9	Right	Population 1930, 1,379.
Ohio River Dam No. 39	529.6	68.5		River gages.
Sampling station	535.1	74.0		
Vevay, Ind	535.2	74.1	Right	Population 1930, 1,183.
Carrollton, Ky	543.4	82.3	Left	Population 1930, 2,409.
Kentucky River	543.4	82.3	do	Drainage area 6,912 square miles.
Sampling station	548.2	87.1		
Brooksburg, Ind	548.3	87.2	Right	Population 1930, 112.
Madison, Ind	555.5	94.4	do	Population 1930, 6,530.
Sampling station	597.8	136.7		
Louisville water works	598.1	137.0	Left	
C. C. C. & St. L. R. R. bridge	600.5	139.4		
Public landing, Louisville	600.6	139.5	Left	
Ohio Falls bridge	602.5	141.4		
Eighteenth Street bridge	602.8	141.7		
Twenty-Seventh Street bridge	604.0	142.9		
Ohio River Dam No. 41	604.0	142.9		River gages.
Ky. & Ind. bridge	604.5	143.4		
New Albany, Ind	604.9	143.8	Right	Population 1930, 25,819.
Sampling station	605.0	143.9		
Do	624.0	162.9		Near Kosmosdale, Ky.

The principal factors responsible for changes in the sanitary condition of the Ohio River below Cincinnati since 1914–1916 may be grouped as follows:

(*a*) Differences in channel conditions resulting from the construction of the additional navigation dams, which increased times of flow and permitted sedimentation during the periods of their operation.

(*b*) Differences in the volume of stream flow during the two periods of observation and especially the combined effects of low stream flow and pool stage in the summer months of high-water temperature.

(*c*) Differences in the population on the watershed resulting in increased sewage pollution, especially in the vicinity of the Cincinnati and Louisville metropolitan areas.

(*d*) Differences in the amount and character of the industrial waste pollution of the river.

DIFFERENCES IN CHANNEL CONDITIONS

At present there are located within the section of the river under observation, navigation dams, No. 37, at Fernbank, Ohio, Mile 481.3; No. 38, at McVille, Ky., Mile 501.3; No. 39, one mile above Markland, Ind., Mile 529.6; and No. 41, at Louisville, Ky., Mile 604.0. Each of the dams, with the exception of No. 41, is of the movable type and is operated as river conditions require. Dam No. 41, a fixed dam, maintains at all times a pool as near elevation 420 as is practicable. During low-water stages these dams form a series of pools with a minimum channel depth of 9 feet.

During the 1914–1916 investigation there was in operation, between Cincinnati and Louisville, Dams 37 and 41, the pool elevation of the latter at that time being 412. Subsequently, it was raised 8 feet to its present elevation, 420. At times of low water, when these dams were in operation, the river flowed through the pool above Dam 37, then under open channel conditions for a distance of approximately 50 miles before entering the upper end of the pool formed by Dam 41 at Louisville.

At present, during periods of relatively high stream flow, when the navigation dams are not required, conditions in the Ohio River between Cincinnati and Louisville are not essentially different from those in 1914–1916, with the exception that the 8-foot increase in elevation of Dam 41 has increased the volume of the pool and lengthened somewhat the time of flow between the two cities. With pool conditions and decreased stream discharge, times of flow between Cincinnati and Louisville have been very materially lengthened.

COMPARISON OF STREAM FLOWS IN 1914–1916 AND 1929–1930

In Table No. 2 there have been tabulated for the three years of the previous survey, 1914, 1915, and 1916, and for the 14 months of the present investigation, November, 1929, to December, 1930, inclusive, the mean monthly yield of the Ohio River watershed above Cincinnati, expressed in terms of inches of depth, on the 70,950 square miles of drainage area.

It will be observed from Table No. 2 that the total run-off (14.17 inches) from the Ohio River watershed in the winter and spring of 1929–30, during open river conditions as represented by the months of November, 1929, to April, 1930, inclusive, was greater than the average of the same months during the three years of the previous investigation, 1914–1916, inclusive (12.49 inches). In the summer and fall months of pool stage, May to December, 1930, inclusive, the total run-off at Cincinnati (1.50 inches) was 23 per cent of the average of the same months in 1914–1916 (6.63 inches).

TABLE NO. 2.—*Run-off from the Ohio River watershed, above the Great Miami River (at Cincinnati), expressed as inches in depth, by months, for the years designated*

Months	Run-off, inches in depth					
	1914	1915	1916	Average, 1914–1916	1929	1930
January	1.56	2.64	4.44	2.88	----------	2.12
February	2.47	3.34	3.00	2.94	----------	1.85
March	2.63	1.23	3.07	2.31	----------	3.30
April	3.61	0.80	3.12	2.51	----------	1.53
May	1.96	0.83	1.49	1.43	----------	0.86
June	0.32	1.07	1.59	0.99	----------	0.36
July	0.30	1.23	0.75	0.76	----------	0.11
August	0.26	0.84	0.70	0.60	----------	0.06
September	0.27	0.79	0.27	0.44	----------	0.07
October	0.25	1.06	0.38	0.56	----------	0.06
November	0.17	0.86	0.26	0.43	2.41	0.09
December	1.16	2.19	0.91	1.42	1.96	0.20
November–April, inclusive	----------	9.11	18.67	12.49	----------	14.17
May–December, inclusive	4.67	8.85	6.37	6.66	----------	1.80

The increase in elevation of Dam 41 and the construction of the additional dams between Cincinnati and Louisville have increased very materially the times of flow between the two cities, the maximum time of flow occurring when all of the dams are in operation. In addition to lengthened times of flow with normal pool conditions, the extremely low discharges in the summer and fall of 1930, produced times of flow very much in excess of those during normal summer periods. It is estimated that with open channel and a run-off of 210,000 second-feet past Cincinnati, the time of flow to Louisville is about 44 hours (1.8 days), while in October, 1930, during pool stage and with an average monthly stream flow of only 3,300 second-feet, the estimated time of flow through the pools was slightly in excess of 1,400 hours (about 58 days).

INCREASE IN POPULATION

In addition to changes in channel conditions since the previous investigation and the minimum stream flows encountered during the summer and fall of the present survey, another factor, namely, the increase in population on the watershed, is significant in comparing conditions at the present time with those of 1914–1916.

On July 1, 1915, the estimated total population on the Ohio River watershed above the Little Miami River, station 461, was 6,933,100, of which 4,042,700 was classed as rural population and 2,890,400 as urban, that is the population living in incorporated communities of 2,500 or over. From the 1930 census the total population on the Ohio River watershed, above the Little Miami River, was 8,160,000, composed of a rural population of 4,209,700 and an urban population of 3,950,300. These figures indicate an increase in total population of 17.7 per cent during the past 15 years. The rural population increased 167,000 and the urban population 1,059,900, equivalent to increases of 14 and 86 per cent, respectively, of the total increase in population. Expressed in another way, the rural population increased 4.1 per cent between 1915 and 1930, while the urban population was increasing 36.7 per cent.

On the watershed of the river between station 461, above Cincinnati, and station 624, below Louisville, the total population increased 432,800 between 1915 and 1930, equivalent to an increase of 19.2 per cent. In this instance the total increase in population (432,800) was made up of an increase in rural population of 51,300, 12 per cent, and an increase in urban population of 381,500, 88 per cent, of the total increase. The rural population increased only 5.2 per cent while the urban population increased 30.2 per cent.

INCREASE IN SEWAGE AND INDUSTRIAL-WASTE POLLUTION

Detailed data are not available relative to the changes in sewered population on the watershed above Cincinnati since the previous survey of the entire main channel. If, however, it is assumed that the proportion of urban population now sewered is the same as in 1915, namely 82 per cent, the approximate number of persons on the watershed above Cincinnati to whom sewerage facilities are available is 3,240,000 as against 2,373,000 in 1915, representing an increase of 867,000 persons, or a 37 per cent increase in sewered population. Within the section of the main stream under observation it is estimated that the population contributing sewage directly to the river is approximately 890,000, an increase of 226,000 since 1915.

In the present investigation, facilities were not available and no attempt was made to obtain data relative to the industrial-waste pollution of the river at Cincinnati and Louisville from which the pollutional factor of manufacturing wastes might be estimated on the basis of equivalent sewered population. Estimates in 1914–1916 of the sewered population equivalent to industrial-waste pollution gave widely varying results, depending on the chemical constituent used in the calculations. It is believed that the biochemical oxygen demand test gives the most significant information in this respect; but since observations of the oxygen demand of industrial wastes were not available in 1914–1916 for comparison with observations made at the present time, no attempt was made to obtain these data.

SECTION II

SOURCES OF POLLUTION

POPULATION ESTIMATES

Estimates of the population on the Ohio River watershed above Cincinnati and within the section of the river under observation, from Cincinnati to Louisville, have been made from the figures of the Fifteenth Census, enumerating the population as of April 1, 1930.

In Table No. 3 there is presented a summary of the estimates of population in 1930 showing its distribution above designated points on the main river as far downstream as the Salt River, below the Louisville metropolitan area, near the lower sampling station of the present investigation. Estimates of population are presented as the total, urban,[4] and rural populations by the various watershed subdivisions.

TABLE No. 3.—*Population as of April 1, 1930, above designated points on the Ohio River watershed*

Watershed	Population		
	Total	Rural	Urban
Allegheny River	1,211,030	691,710	519,320
Monongahela River	1,231,220	663,500	567,720
Above Pittsburgh	2,442,250	1,355,210	1,087,040
Beaver River	698,940	228,080	470,860
Ohio River direct, Pittsburgh to Wheeling	1,318,810	336,590	982,220
Above Wheeling	4,460,000	1,919,880	2,540,120
Muskingum River	790,650	386,840	403,810
Ohio River direct, Wheeling to Parkersburg	278,660	155,510	123,150
Above Parkersburg	5,529,310	2,462,230	3,067,080
Little Kanawha River	85,490	85,490	----------
Hocking River	106,900	62,730	44,170
Ohio River direct, Parkersburg to Point Pleasant	97,120	53,320	43,800
Above Point Pleasant	5,818,810	2,663,760	3,155,050
Great Kanawha River	708,030	566,420	141,610
Big Sandy River	343,080	316,460	26,620
Little Sandy River	34,050	34,050	----------
Guyandotte River	120,800	116,400	4,400
Raccoon Creek	25,250	19,930	5,320
Ohio River direct, Point Pleasant to Portsmouth	257,070	117,860	139,210
Above Portsmouth	7,307,090	3,834,880	3,472,210
Scioto River	712,440	283,510	428,930
Ohio River direct, Scioto to Little Miami River	140,470	91,350	49,120
Above Little Miami River	8,160,000	4,209,740	3,950,260
Little Miami River	120,820	99,120	21,700
Licking River	173,460	154,410	19,050
Ohio River direct, Little Miami to Great Miami River	698,710	36,130	662,580
Above Great Miami River	9,152,990	4,499,400	4,653,590
Great Miami River	782,920	296,210	486,710
Ohio River direct, Great Miami to Kentucky River	54,510	43,210	11,300
Above Kentucky River	9,990,420	4,838,820	5,151,600
Kentucky River	432,620	339,900	92,720
Ohio River direct, Kentucky River to Louisville	28,010	21,480	6,530
Above Louisville	10,451,050	5,200,200	5,250,850
Ohio River direct at Louisville	361,650	16,140	345,510
Ohio River direct, Louisville to Salt River	31,230	31,230	----------
Above Salt River	10,843,930	5,247,570	5,596,360
Ohio River between Little Miami River and Salt River	2,683,930	1,037,830	1,646,100

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[4] In these tabulations the urban population is assumed as the number of persons living in incorporated communities of 2,500 population or over. The rural population is the remaining population of the watershed.

Table No. 3 indicates that there was an estimated total population of 8,160,000 on the Ohio River watershed above the Little Miami River on April 1, 1930, made up of a rural population of 4,209,700, about 52 per cent of the total, and an urban population of 3,950,300, about 48 per cent of the total. Between the upper and lower sampling stations of the present investigation, which includes the metropolitan areas of Cincinnati and Louisville, there was an estimated total population of 2,683,900, consisting of a rural population of 1,037,800, about 39 per cent, and an urban population of 1,646,100, about 61 per cent of the total.

The estimated total population within the Cincinnati and Louisville metropolitan areas on April 1, 1930, was 721,900 and 379,800 respectively.

In Table No. 4 there have been brought together for comparison 1915 and 1930 estimates of population on the Ohio River, above the Little Miami, and on the watershed between the Little Miami and Salt Rivers, the section of the river under observation. Populations on these two main divisions of the watershed have been further divided to compare the 1915 and 1930 estimates of population on the larger tributaries at some distance from the main channel with the estimated populations directly on or close to the main stream.

TABLE No. 4.—*Comparison of 1915 estimated populations with those of 1930, on designated subdivisions of Ohio River watershed*

Watershed area	Population		
	Total	Rural	Urban
Ohio River above the Little Miami River			
Population on larger tributaries: [1]			
1915	5,087,400	3,252,100	1,835,300
1930	6,008,500	3,401,100	2,607,400
Percentage increase, 1915 to 1930	18.1	4.6	42.1
Population directly on Ohio River or minor tributaries:			
1915	1,845,700	790,600	1,055,100
1930	2,151,500	808,600	1,342,900
Percentage increase, 1915 to 1930	16.6	2.3	27.3
Total population above Little Miami River:			
1915	6,933,100	4,042,700	2,890,400
1930	8,160,000	4,209,700	3,950,300
Percentage increase, 1915 to 1930	17.7	4.1	36.7
Ohio River between Little Miami and Salt Rivers (section under observation)			
Population on larger tributaries: [2]			
1915	1,271,300	840,800	430,500
1930	1,509,800	889,600	620,200
Percentage increase, 1915 to 1930	18.8	5.8	44.1
Population directly on Ohio River or minor tributaries:			
1915	979,800	145,800	834,000
1930	1,174,100	148,200	1,025,900
Percentage increase, 1915 to 1930	19.8	1.6	23.0
Total population between Little Miami and Salt Rivers:			
1915	2,251,100	986,600	1,264,500
1930	2,683,900	1,037,800	1,646,100
Percentage increase, 1915 to 1930	19.2	5.2	30.2

[1] Includes the Allegheny, Monongahela, Beaver, Muskingum, Little Kanawha, Hocking, Great Kanawha, Big Sandy, Guyandotte, and Scioto Rivers.

[2] Includes the Little Miami, Licking, Great Miami, and Kentucky Rivers.

The data of Table No. 4 indicate that the total population of the entire watershed above Cincinnati increased 17.7 per cent between 1915 and 1930, the urban population 36.7 per cent, and the rural population 4.1 per cent. Subdividing the total population into that on the larger tributaries, which is more or less distant from the main channel, and that located directly along the main stream, Table No. 4 indicates that on the tributaries the total population increased 18.1 per cent, the urban population 42.1 per cent, and the rural population 4.6 per cent, while the total population directly tributary to the main stream increased 16.6 per cent, the urban population 27.3 per cent, and the rural population 2.3 per cent.

For the section of the river under observation, from above Cincinnati to below Louisville (Little Miami to the Salt River), the total population increased 19.2 per cent between 1915 and 1930, the urban population 30.2 per cent, and the rural population 5.2 per cent. Subdividing this population as before, that is, taking the population on the tributaries more or less distant from the main channel and that contributing directly to the main stream, the total population of the combined tributary areas increased 18.8 per cent, the urban population 44.1 per cent, and the rural population 5.8 per cent, while similar increases for the population directly adjacent to the main channel were, total population 19.8 per cent, urban 23.0 per cent, and rural 1.6 per cent.

Actual increases in population on the upper watershed above Cincinnati between 1915 and 1930, were: Total population 1,226,900; urban population 1,059,900, equal to 86 per cent; and rural population 167,000, or 14 per cent of the total increase.

Within the section of the river under observation the total population on the watershed increased 432,800, and was made up of an increase in urban population of 381,600, equal to 88 per cent of the total, and an increase in rural population of 51,200, equivalent to 12 per cent of the total increase.

It is estimated that the increases in population between 1915 and 1930 directly tributary to the main stream, from above Cincinnati to below Louisville, were: Total population 194,300; urban population 191,900, or 98.8 per cent of the total increase; and rural population 2,400, about 1.2 per cent of the total increase.

SEWERED POPULATION

Detailed data are not available relative to the sewered population on the watershed above Cincinnati. At the time of the 1915 survey it was ascertained that approximately 82 per cent of the total urban population on the watershed above the Little Miami River contributed sewage to the drainage system, a figure not greatly different from the percentage of the urban population sewered on the Illinois River watershed in 1922 and on the upper Mississippi River watershed in 1926. Applying this figure of 82 per cent to the total urban population on the Ohio River watershed above Cincinnati in 1930, the estimated sewered population above this point would be approximately 3,240,000 as against 2,370,000 in 1915, an increase of nearly 37 per cent in sewered population in the past 15 years.

Between the upper and lower sampling stations of the present survey the total sewered population contributing directly to the main stream is estimated at approximately 890,000, of which 601,000 is located within the Cincinnati metropolitan area, 285,000 within the Louisville area, and approximately 4,000 directly tributary to the main river between these two metropolitan districts. During the past 15 years the sewered population within this section of the stream has increased about 33 per cent, the greatest increase occurring within the Louisville area due to an extensive program of sewerage construction during the past few years, which is still in progress.

INDUSTRIAL WASTE POLLUTION

In the present resurvey of the Ohio River the facilities necessary for a comprehensive study of the industrial waste pollution of the stream have not been available and no estimates of the effect of these wastes on the river, in terms of equivalent sewered population, have been attempted. Undoubtedly, changes in the industrial waste pollution of the river within the Cincinnati-Louisville area have taken place since the previous study in 1914–1916. Probably the greatest single factor influencing changes within this section has been the removal of the large amounts of highly putrescible brewing and distilling wastes as a result of the cessation of operation of these organized industries.

While it has been impossible to estimate the improvement due to the removal of a particular waste or wastes, or the effect of increasing waste pollution due to growth of the older industries, or of new manufacturing processes, the net result of all of the changes in pollution, including the effect of domestic sewage, is reflected in general by the changes in the chemical and bacteriological findings that have taken place since the previous investigation, at sampling points immediately below these centers of industrial activity.

SECTION III

HYDROMETRIC STUDIES

For the proper quantitative interpretation of the chemical and bacteriological findings, it has been necessary to secure fairly accurate estimates of stream flow at each of the various sampling points on the main stream and at the mouths of tributaries, at all river stages during the period of the investigation. Discharge measurements have further been utilized to estimate times of flow in the main channel through and below the Cincinnati metropolitan area, in order that the chemical and bacteriological results might be interpreted in terms of the rate of change between successive downstream points.

The hydrometric data, therefore, are presented as summaries, in the form of monthly averages, giving:

(1) The mean discharge, in cubic feet per second (second-feet) at each sampling station on the main river and at the mouths of the tributaries entering between Cincinnati and Louisville, and

(2) The estimated mean times of flow: (*a*) Between successive sampling stations or other designated points from above Cincinnati to below Louisville, and (*b*) as cumulative times of flow through the Cincinnati metropolitan area, and from the lower limits of the Cincinnati district to the Louisville water-works intake, above Louisville.

DISCHARGE ESTIMATES

Estimates of the daily discharge of the Ohio River at Cincinnati and Louisville are available at the district engineer's office, United States Army Engineer Corps. Estimates of the run-off from the Little Miami, Licking, Great Miami, and Kentucky River watersheds are available from the records of the United States Geological Survey, water resources branch, from rating stations maintained by their own organization or in cooperation with other agencies.

Gaging stations on tributaries in all instances are located at considerable distances above their mouths, and in estimating the discharge at their points of confluence with the main stream it has been assumed that the run-off, per square mile of drainage area, was the same below the point of measurement as the yield per square mile above the gaging station.

In estimating the discharge at the several sampling stations along the main river between Cincinnati and Louisville, the section was divided into a number of prisms of varying length with limits at sampling points, at the mouths of tributaries or at points of definite change in depth, width, or slope of the river. Areas of the watershed at the upper and lower limits of each prism were determined in such a manner that the portion draining through the rated tributaries could be separated from that draining more directly into the main stream. Discharges through the various prisms were then estimated from the discharge at Louisville and from the tributaries, by working either up or down stream from the rating section and deducting or adding the discharge of tributaries and the run-off from the drainage area immediately adjacent to the river. During periods of open channel, the discharge computed at Cincinnati from the

Louisville record checked within less than 10 per cent of that estimated from the Cincinnati rating curve for open-river conditions and averaged 5 per cent during the 6-month period when the dams were down.

At pool stage, estimates of discharge at Cincinnati appear to be subject to considerable error and it is believed that the discharge estimates at Louisville at such times, which are obtained from powerhouse records and the flow over the weirs and through the locks of Dam No. 41, are more representative of low-water conditions than are the flows estimated at Cincinnati. At times of pool stage therefore, during the 8-month period May to December, 1930, pool stage flows at Cincinnati have been estimated from the discharge at Louisville and the contributions of the several tributaries entering above that station.

Tables Nos. 5 and 6 summarize the monthly average discharges at various designated points along the river between Cincinnati and Louisville. Table No. 5 shows the monthly mean discharge, in second-feet, at the mouths of the larger tributaries entering the main river in the section under observation, and Table No. 6 the monthly mean rates of discharge at the various sampling points and above and below tributaries on the main river.

Table No. 5.—*Monthly average rates of discharge, in cubic feet per second, of the Little Miami, Licking, Great Miami, and Kentucky Rivers, at their mouths*

Month	Tributary			
	Little Miami River (1,714 square miles)	Licking River (3,[illegible] square miles)	Great Miami River (5,410 square miles)	Kentucky River (6,913 square miles)
1929				
November	3,570	8,770	4,830	10,730
December	2,190	2,910	5,730	7,460
1930				
January	5,[illegible]	7,810	26,900	8,930
February	2,[illegible]	5,[illegible]	10,670	13,[illegible]
March	2,[illegible]	4,740	6,[illegible]	9,[illegible]
April	1,[illegible]	1,[illegible]	3,570	3,720
May	[illegible]	720	1,670	2,[illegible]
June	130	102	1,280	[illegible]
July	33	19	722	[illegible]
August	83	16	683	[illegible]
September	142	14	878	118
October	65	6	746	129
November	78	12	689	[illegible]
December	98	45	756	318
AVERAGES				
Year 1930	1,180	2,020	4,610	3,870
November, 1929, to April, 1930	2,[illegible]	5,670	10,240	9,[illegible]
May to November, 1930	131	126	861	622

TABLE No. 6.—*Average monthly rates of discharge, cubic feet per second, at designated points on the Ohio River between Cincinnati and Louisville, November, 1929, to December, 1930*

Month	Station [illegible] above Little Miami River ([illegible] square miles)	Above Licking River¹ ([illegible] square miles)	Station 475² ([illegible] square miles)	Station [illegible] above Great Miami River ([illegible] square miles)	Station [illegible] below Great Miami River ([illegible] square miles)	Station [illegible] ([illegible] square miles)	Station [illegible] ([illegible] square miles)	Above Kentucky River ([illegible] square miles)	Station [illegible] below Kentucky River ([illegible] square miles)	Station [illegible] above Louisville, Ky.³ ([illegible] square miles)
1929										
November	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
December	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1930										
January	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
February	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
March	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
April	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
May	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
June	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
July	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
August	[illegible]	[illegible]	[illegible]	[illegible]	7,000	7,700	7,700	7,700	[illegible]	[illegible]
September	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
October	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
November	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
December	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AVERAGE										
Year 1930	[illegible]	[illegible]	[illegible]	[illegible]	67,400	[illegible]	68,270	68,340	71,020	[illegible]
November, 1929, to April, 1930	[illegible]	[illegible]	157,670	145,225	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
May to November, 1930	11,640	11,700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] Discharge below Little Miami River assumed the same as the discharge above the Licking River.
[2] Discharge below Licking River assumed the same as that at station 475.
[3] Discharge at stations [illegible] and [illegible] below Louisville assumed same as at Louisville, since increase in watershed area equals only [illegible] square miles.

During the 6-month period, November, 1929, to April, 1930, the discharge of the Ohio River drainage basin was such that the navigation dams were not required and the river flowed past Cincinnati under open-river conditions. From May to December, 1930, the rainfall on the watershed was considerably below the normal, resulting in decreased run-off, which reached a minimum in October at Cincinnati, the flow during this month averaging only 3,360 second-feet. For the 5-month period, July to November, 1930, inclusive, the average monthly discharge of the Ohio River at Cincinnati was only 5,000 second-feet. As a result of the decreased stream flow, the navigation dams on the main stream were in continuous operation during the 10-month period, May, 1930, to February, 1931, inclusive. After March, 1931, stream flows were again in excess of 100,000 second-feet and more normal conditions prevailed in the watercourse.

Average monthly stream flows during the period of the investigation have been subdivided into a combined winter and spring period, consisting of the six months, November, 1929, to April, 1930, inclusive, representing conditions with stream flows in the main channel in excess of 100,000 second-feet, and a combined summer and fall period, represented by the 7-month period, May to November, 1930, inclusive, during which the river was continuously at pool stage and the average monthly flows were 35,000 second-feet or less.

The effect of the deficiency in rainfall in the summer and fall of 1930 is clearly indicated by the decreased discharge of the main stream and the larger tributaries toward the end of the year. Discharge records for the tributaries suggest that the effects of decreased precipitation were more noticeable on the tributaries entering from the south through Kentucky (the Licking and Kentucky Rivers) than on those entering from the north through Ohio—the Little and Great Miami Rivers. The minimum average monthly discharge of the Kentucky River, with a watershed area of 6,912 square miles, was 115 second-feet in September; that of the Licking River, watershed area 3,636 square miles, was 6 second-feet in October. The minimum average monthly discharge of the Great Miami River, watershed area 5,410 square miles, was 682 second-feet in August and 688 second-feet in November; while that of the Little Miami, watershed 1,714 square miles, was 65 second-feet in October. In other words, the Great Miami River, with a watershed area equivalent to 78 per cent of that of the Kentucky River, contributed six times the amount of run-off during the months of minimum discharge; while the Little Miami River, with a watershed equal to 47 per cent of that of the Licking River, contributed nearly eleven times the flow of the Licking River during October.

Comparing the average seasonal discharge in summer, at pool stage, with the mean winter discharge when the navigation dams were down, the summer flows of the Little Miami, Licking, Great Miami, and Kentucky Rivers were approximately 4.0, 2.0, 9.0, and 6.0 per cent, respectively, of the average winter flows. In the main channel the mean summer flow was about 7.5 per cent of the mean winter flow.

TIME OF FLOW ESTIMATES

In Table No. 7 there are summarized the calculated times of flow, in hours, between various points on the Ohio River from Cincinnati to Louisville, and in Table No. 8 the cumulative times of flow through the Cincinnati metropolitan district, station 461 to station 475, and from station 475 to successive sampling points downstream to Louisville.[8]

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[8] Times of flow were estimated from the mean discharge and cross-sectional area. The river was divided into a number of prisms ending at sampling points, tributaries, dams, etc. Several representative cross sections in each prism were determined from soundings and plotted to scale. Wetted areas were next determined for the several individual cross sections at a number of gage readings between low and high water, assuming the water-surface level. Mean cross-sectional areas were then determined by weighting individual areas by the distance between sections, giving a gage height—mean area relationship with the water-surface level. A correlation of gage heights above and below the prism indicated changes in water slopes with varying gage readings, so that gage-area relationships with water-surface level could be corrected for sloping water surfaces. Having determined the discharge and mean cross-sectional area for various readings of the reference gage, mean velocities of flow could be ascertained, from which times of flow were calculated from the length of the prism. The end result was a series of gage height-time of flow curves applicable to the entire section of the river. During periods of pool stage when the river was maintained at a predetermined elevation, times of flow through the pools were estimated from their total volume, at pool elevation, and the mean monthly discharge, assuming the time of flow as the time required to completely displace the water of the pool.

TABLE No. 7.—*Estimated mean monthly times of flow, in hours, between designated points on the Ohio River from Cincinnati to Louisville, November, 1929, to December, 1930*

Month	461 to Little Miami	Little Miami to Licking	Licking to 475	475 to 486	486 to Great Miami	Great Miami to 493	493 to 508	508 to 533	533 to Kentucky	Kentucky to 548	548 to 598
1929											
November	1.1	2.2	1.8	5.3	1.4	0.5	5.0	15.5	2.7	2.8	17.2
December	1.2	2.4	2.0	5.2	1.6	0.3	6.0	18.7	3.3	2.8	19.0
1930											
January	1.0	2.0	1.7	4.9	1.0	0.3	4.4	13.6	3.4	2.3	15.0
February	1.1	2.4	2.0	6.2	1.1	0.4	4.8	18.8	3.2	2.7	18.7
March	1.0	2.0	1.6	4.7	1.0	0.3	4.3	13.2	2.3	2.3	15.6
April	1.3	2.6	2.2	6.4	1.2	0.5	7.2	22.1	2.9	4.0	21.7
May	0.8	5.5	3.3	10.8	0.7	1.5	11.4	24.0	5.5	11.4	81.0
June	1.1	5.4	7.9	16.3	1.1	2.7	17.6	36.6	8.3	18.8	130.0
July	2.7	18.5	27.5	62.0	3.7	7.2	56.4	119.5	27.0	89.0	390.0
August	6.4	33.0	48.0	98.0	6.7	12.5	96.9	199.5	44.0	94.0	680.0
September	5.2	27.0	40.0	51.0	5.4	10.0	78.7	161.5	67.0	78.0	560.0
October	7.4	39.0	55.0	114.0	7.7	14.0	109.0	222.0	49.0	108.0	780.0
November	4.5	23.0	34.0	69.0	4.7	9.0	73.8	149.7	33.0	71.0	519.0
December	2.0	9.7	14.2	29.3	1.9	4.0	31.0	64.8	15.0	33.0	290.0

AVERAGE

Month	461 to Little Miami	Little Miami to Licking	Licking to 475	475 to 486	486 to Great Miami	Great Miami to 493	493 to 508	508 to 533	533 to Kentucky	Kentucky to 548	548 to 598
November to April	1.1	2.3	1.9	5.5	1.1	0.4	5.5	16.8	3.0	2.6	17.9
May to November	4.2	21.2	31.2	64.4	4.3	8.1	62.0	139.8	39.0	65.0	461.6

TABLE No. 8.—*Cumulative mean monthly times of flow, in hours, through the Cincinnati metropolitan area, stations 461 to 475, and below the Cincinnati metropolitan area to Louisville, stations 475 to 598, November, 1929, to December, 1930*

Month	Time of flow through the Cincinnati metropolitan area, station 461 to 475	Cumulative times of flow below sampling station 475 to: Station 475	Station 482	Station 486	Station 493	Station 508	Station 533	Station 548	Station 598
1929									
November	5.1	0	2.0	5.3	7.2	12.2	27.7	33.2	50.4
December	5.6	0	2.3	5.2	7.1	13.1	31.8	37.9	56.9
1930									
January	4.7	0	2.0	4.9	6.2	10.6	24.2	29.9	44.9
February	5.5	0	3.3	6.2	7.7	12.5	31.3	37.2	55.9
March	4.6	0	2.7	4.7	6.0	10.3	23.5	28.1	43.7
April	6.1	0	3.7	6.4	8.1	15.3	37.4	44.3	66.0
May	9.6	0	5.8	10.8	13.0	24.4	48.4	65.3	146.3
June	14.4	0	8.8	16.3	20.1	37.7	74.3	101.4	231.4
July	48.7	0	33.5	62.0	72.9	129.3	248.8	364.8	754.8
August	87.4	0	52.9	98.0	117.2	214.1	413.6	551.6	1,231.6
September	72.2	0	43.7	51.0	66.4	145.1	306.6	451.6	1,011.6
October	101.4	0	61.6	114.0	135.7	244.7	466.7	623.7	1,403.7
November	61.5	0	37.3	69.0	82.7	156.5	306.2	410.2	929.2
December	25.9	0	15.8	29.3	35.2	66.2	131.0	179.0	469.0

AVERAGE

Month	Time of flow through the Cincinnati metropolitan area, station 461 to 475	Station 475	Station 482	Station 486	Station 493	Station 508	Station 533	Station 548	Station 598
November to April	5.3	0	3.1	5.5	7.0	12.5	29.3	34.9	52.8
May to November	56.6	0	34.8	64.4	76.8	138.8	278.6	382.6	844.2

Tables Nos. 6 and 7 both indicate the effect of the low stream flows in the summer and fall, with the river at pool stage. In the winter period of open river the mean time of flow during the months of November, 1929, to April, 1930, through the Cincinnati metropolitan district, stations 461 to 475, was 5.3 hours, varying between 4.6 and 6.1 hours. With the decreased run-off toward the end of 1930, the average time of flow during the months of May to November was 56.6 hours, or over ten times that of the winter period. During the month of lowest stream flow, October, 1930, the time of flow through the Cincinnati area was in excess of 100 hours.

Times of flow from the lowest of the Cincinnati sewer outlets to Louisville, with the relatively high flows of winter and the movable dams out of operation, averaged about 53 hours, 2.2 days, while during pool conditions in the summer the mean time of flow was about 814 hours, or nearly 34 days. In October, the month of lowest stream flow, the theoretical time of flow from Cincinnati to Louisville was slightly over 1,400 hours, or nearly 58¼ days.

Times of flow in the various sections of the river have been utilized in an attempt to study the effect on the rates of chemical and bacteriological changes under these widely different conditions of river channel and stream flow.

SECTION IV

COLLECTION AND ANALYSIS OF SAMPLES

During the present investigation, 11 sampling stations were maintained on the main river, between the upper limits of the Cincinnati metropolitan area and the lower limits of the Louisville metropolitan area, and 4 stations at the mouths of the larger tributaries entering this section of the river.

The following tabulation shows the location of the various sampling stations in their order downstream from the uppermost station opposite the Cincinnati waterworks intake. Stations on the tributaries have been inserted between those on the main river, designating the section in which they enter.

SAMPLING STATIONS

Station No. 461.—On Ohio River, immediately above the Cincinnati metropolitan district, opposite the waterworks.

Station "Little Miami."—On Little Miami River, about one-half mile above the mouth.

Station "Licking."—On Licking River, about 3 miles above mouth.

Station No. 475.—On Ohio River, below the Cincinnati sewer outlets and 6.3 miles above Dam No. 37.

Station No. 482.—On Ohio River, about 0.7 mile below Dam No. 37.

Station No. 488.—On Ohio River, immediately above the mouth of the Great Miami River, 6.7 miles below Dam No. 37.

Station "Miami."—On Great Miami River, just above the mouth.

Station No. 492.—On Ohio River, 2.6 miles below the confluence of the Great Miami River, and 9.3 miles above Dam No. 38.

Station No. 503.—On Ohio River, just above Rising Sun, Ind., and 1.7 miles below Dam No. 38.

Station No. 535.—On Ohio River, just above Vevay, Ind., 5.4 miles below Dam No. 39, and 8.4 miles above the mouth of the Kentucky River.

Station "Kentucky."—On Kentucky River, near its mouth, at Carrollton, Ky.

Station No. 548.—On Ohio River, just above Brooksburg, Ind., 4.6 miles below the mouth of the Kentucky River.

Station No. 598.—On Ohio River, immediately above Louisville, Ky., opposite the waterworks.

Station No. 605.—On Ohio River, opposite New Albany, Ind., about 1 mile below Dam No. 41.

Station No. 624.—On Ohio River, at Kosmosdale, Ky., 3 miles above the mouth of the Salt River.

With the exception of stations Nos. 503 and 535, below Cincinnati, and stations Nos. 605 and 624, below Louisville, the location of sampling stations during the 1929–1931 investigation was the same as at the time of the previous investigation in 1914–1916. Stations Nos. 503 and 535 were added at the present time to indicate more clearly conditions in the main river between the Great Miami and Kentucky Rivers, while stations Nos. 605 and 624 were selected at different points below Louisville in an attempt to indicate somewhat better the effects of pollution from the Louisville area.

COLLECTION OF SAMPLES

Samples for chemical and bacteriological analysis were collected regularly from stations Nos. 461 to 535, inclusive, during the 14-month period, November, 1929, to December, 1930, inclusive; from the station on the Kentucky River and at station No. 548 on the main river during the 7-month period, June to December, 1930, inclusive; and from stations Nos. 598 to 624, inclusive, during the 13-month period, May, 1930, to May, 1931, inclusive.

Samples from main river station, 461, and from the Little Miami and Licking Rivers, were collected twice each week, on Tuesday and Thursday. Samples from all other main river and tributary sampling stations were collected three times each week, on Monday, Wednesday, and Friday.

At each of the main river sampling stations, water samples were collected from three points on the sampling section,[6] but samples from the tributaries were collected at a single point, in the channel at mid-depth.

Chemical and bacteriological samples were taken in a special collecting device,[7] holding one bottle for the bacteriological sample and two bottles for the chemical determinations.

Samples collected from stations Nos. 461 to 482, inclusive, located within the Cincinnati area, were brought immediately by automobile to the Cincinnati laboratory, and samples collected at stations Nos. 598 to 624, inclusive, within the Louisville district, by automobile to the Louisville laboratory. From stations Nos. 488 to 535, inclusive, samples were transported by bus to Cincinnati, and from the Kentucky River and station No. 548, by bus to Louisville. During the summer period all samples shipped by bus were iced immediately after collection.

LABORATORY PROCEDURE

Routine chemical analyses consisted in determining the alkalinity, turbidity, initial dissolved oxygen, and the 5-day biochemical oxygen demand at 20° C. For varying periods during the progress of the investigation, hydrogen-ion determinations were made at each sampling point. Bacteriological examinations consisted in determining the number of organisms growing on agar at 37° C. in 24 hours and making an estimate of the number of organisms of the coli-aerogenes group present in each sample.

For a period of about one month, at the beginning of the study, two methods of analysis were employed where the sample from a single river section consisted of three separate portions: (*a*) Each portion was analyzed separately and the individual results averaged for the final determination, and (*b*) compositing equal amounts of the three separate portions to make a single sample prior to analysis. Since the results were essentially the same by either method, the compositing of samples, for all determinations with the exception of initial dissolved oxygen, was adopted as standard procedure. For a 7-month period, November, 1929, to May, 1930, inclusive, the average monthly alkalinities and turbidities were determined from the average of the daily results obtained during the month. After May, 1930, monthly average alkalinities and turbidities were determined from a single sample at the end of the month, made up of equal portions of the daily samples.

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[6] Three points on a sampling section were located by calculating the cross-sectional area of the river at the mean water-surface elevation, dividing this area into three equal parts and locating sampling points at mid-depth in the center of each equal subdivision. Sampling depths were varied with changes in the water-surface elevation, and all sampling points were located by shore ranges.

[7] A description and sketch of the sampling device used is contained in Public Health Bulletin No. 171, A Study of the Pollution and Natural Purification of the Illinois River, pp. 57–58.

With the exception of the oxygen demand determination, all chemical and bacteriological examinations were made in accordance with Standard Methods for the Examination of Water and Sewage, and the results of present and past analyses are entirely comparable. During the present investigation, oxygen demands were ascertained for a period of 5 days at 20° C., rather than after a period of 24 hours as in the case of the 1914–1916 investigation. All oxygen demand determinations were made in accordance with the procedure outlined by Principal Chemist E. J. Theriault,[8] United States Public Health Service. In the few instances where the dilution of samples was required prior to incubation, phosphate dilution water was used.[9]

The number of organisms of the coli-aerogenes group in each sample was determined by the partially confirmed test and no attempt was made to differentiate between the types of organisms present. The results have therefore been reported as the number of coli-aerogenes group organisms present in the sample.

SECTION V

CHEMICAL ANALYSES

BASIC TABULATIONS

During the present investigation of the Ohio River, covering the months of November, 1929, to May, 1931, inclusive, samples for chemical analysis were collected from the various river sections as follows:

Sampling station	Period of collection	Number of samples
461 to 535, inclusive	November, 1929, to December, 1930, inclusive	1,264
548 and Kentucky River	June to December, 1930, inclusive	141
588 to 624, inclusive	May, 1930, to May, 1931, inclusive	410
Total chemical samples collected		1,796

The results of the analysis of daily samples are presented in the form of monthly averages in the basic tabulation, Table No. 9, which summarizes the chemical results by sampling stations for each month of the investigation. Included in the table are other related data, such as the mean monthly rates of stream flow and monthly averages of water temperatures.

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[8] The Oxygen Demand of Polluted Waters, by E. J. Theriault, Public Health Bulletin No. 173, Appendix III, and Detailed Instructions for the Performance of the Dissolved Oxygen and Biochemical Oxygen Demand Tests, by E. J. Theriault, Supplement No. 90 to the Public Health Reports.

[9] Experimental Studies of Natural Purification in Polluted Waters; V. The selection of dilution waters for use in oxygen demand tests. Reprint No. 1475 from the Public Health Reports. E. J. Theriault, Chemist, Paul D. McNamee, Technical Assistant and C. T. Butterfield, Bacteriologist, United States Public Health Service.

In a detailed study of the changes in dissolved oxygen and oxygen demand, variations in the actual amounts of the constituents are of greater significance than changes in the concentration. Actual amounts [a] of dissolved oxygen and oxygen demand, expressed as the daily average for the month, in pounds, at the various sampling stations, are also presented in Table No. 9.

TABLE No. 9.—*Summary of monthly average results of chemical analyses at each sampling station, arranged by months*

SAMPLING STATION 461.—OHIO RIVER ABOVE CINCINNATI, 1 MILE ABOVE THE MOUTH OF LITTLE MIAMI RIVER

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	153,100	6	9.8	35	177	7.3	9.70	85.2	2.36	8,019,380	1,951,110
December	120,400	8	2.5	40	116	7.4	12.96	94.9	1.81	8,426,070	1,176,790
1930											
January	192,100	7	3.9	37	122	7.3	12.45	94.6	2.05	12,914,880	2,126,550
February	125,900	8	4.1	44	187	7.4	12.72	97.1	2.33	8,647,820	1,677,300
March	203,300	8	6.4	31	173	7.2	11.65	94.3	2.11	12,789,600	2,316,400
April	97,400	9	11.6	40	67	7.4	10.27	94.0	1.61	5,401,610	846,800
May	34,600	9	20.1	40	19	7.4	9.11	99.5	1.73	1,702,110	323,230
June	22,900	8	22.9	66	5	------	8.95	105.3	1.80	1,106,760	222,700
July	6,800	10	24.9	44	5	------	8.16	100.9	1.73	299,640	63,530
August	3,820	7	25.4	47	8	------	8.49	102.1	1.30	175,130	26,820
September	4,680	9	23.4	60	7	------	8.40	97.4	1.64	212,280	41,450
October	3,290	9	16.1	70	5	------	9.58	96.5	1.21	170,200	21,500
November	5,480	7	9.2	67	5	------	11.23	97.3	1.36	332,320	40,250
December	12,510	6	2.6	58	7	------	12.98	95.8	1.78	876,850	120,250

AVERAGES

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
Year 1930	59,390	------	14.5	50	48	------	10.34	97.9	1.73	3,719,220	645,520
November, 1929, to April, 1930	148,700	------	6.4	38	135	7.3	11.63	95.3	2.04	9,336,560	1,665,620
May to November, 1930	11,640	------	20.7	56	7	------	9.14	99.9	1.56	571,410	108,440

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[a] Various chemical constituents, expressed in terms of concentration, parts per million, may be converted into actual amounts, pounds per day by the following expression:

QUANTITY (pounds daily)=DISCHARGE (second-feet) ×5.4 (factor) ×p.p.m

In this expression, 5.4 is the conversion factor for changing a flow of 1 cubic foot per second into millions of pounds of water per day (62.5, weight of 1 cubic foot of water times 86,400, seconds per day, divided by 1,000,000).

TABLE No. 9.—*Summary of monthly average results of chemical analyses, etc.*

SAMPLING STATION—LITTLE MIAMI RIVER, ONE-HALF MILE ABOVE MOUTH

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	3,540	7	7.7	164	303	8.0	10.84	90.6	3.61	307,220	69,010
December	3,180	7	3.1	175	154	7.8	12.64	94.0	2.64	217,080	45,230
1930											
January	5,880	9	3.8	191	138	7.9	12.53	94.8	3.01	377,030	90,860
February	3,960	8	5.4	172	605	7.9	12.43	98.0	3.35	266,930	72,060
March	2,330	8	6.0	214	37	8.1	11.53	92.4	2.79	145,070	35,100
April	1,200	9	12.5	201	71	8.1	9.73	90.8	3.71	63,080	24,040
May	300	9	19.5	239	24	8.0	6.59	71.6	4.59	11,000	7,680
June	159	8	23.1	233	6	......	3.22	37.2	6.26	2,760	5,370
July	82	10	24.3	195	5	......	1.07	12.5	8.83	470	3,910
August	82	7	23.4	201	10	......	1.33	15.4	11.21	500	4,980
September	142	9	21.7	160	70	......	2.98	33.6	8.76	2,290	6,720
October	65	9	13.8	191	15	......	1.90	18.2	11.26	670	3,980
November	75	7	8.6	224	15	......	2.08	17.5	13.41	550	5,500
December	96	8	1.8	234	10	......	8.28	60.1	16.33	4,270	9,800
AVERAGES											
Year 1930	1,180	......	13.7	217	84	......	6.13	53.5	7.97	72,990	22,470
November, 1929, to April, 1930	3,200	......	6.4	196	218	8.0	11.61	93.4	3.18	212,880	56,080
May to November, 1930	131	......	19.2	230	21	......	2.74	29.5	9.21	2,670	5,440

SAMPLING STATION—LICKING RIVER ABOUT 3 MILES ABOVE MOUTH

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	6,770	7	9.6	125	157	7.7	10.39	90.9	3.18	379,840	116,230
December	3,910	7	2.9	111	290	7.8	13.14	97.2	2.47	277,440	52,180
1930											
January	7,810	9	4.2	116	318	7.6	12.79	97.9	2.38	539,410	100,370
February	8,940	8	6.5	90	698	7.6	12.16	98.7	2.78	587,040	134,210
March	4,740	8	7.4	102	71	7.9	11.52	95.6	1.93	294,870	49,400
April	1,830	9	13.8	99	136	7.9	10.01	96.1	3.22	98,930	31,820
May	700	9	21.1	99	114	7.9	7.78	86.7	3.10	29,410	11,720
June	105	8	24.6	144	53	......	7.44	88.2	4.54	4,140	2,580
July	19	10	27.3	110	25	......	7.68	95.7	5.80	790	600
August	16	7	25.2	116	32	......	6.66	79.8	10.62	580	920
September	14	8	24.8	111	130	......	5.64	67.1	7.71	430	580
October	6	9	15.9	113	35	......	9.22	92.5	12.15	300	390
November	13	7	9.8	122	28	......	8.45	74.2	12.75	590	900
December	45	7	3.7	125	7	......	6.89	52.1	11.69	1,670	2,840
AVERAGES											
Year 1930	2,020	......	15.4	112	128	......	8.86	85.4	6.86	129,850	24,690
November, 1929, to April, 1930	5,670	......	7.4	107	250	7.8	11.67	96.1	2.66	362,920	80,700
May to November, 1930	134	......	21.2	116	60	......	7.85	83.5	8.10	5,180	2,830

Table No. 9.—*Summary of monthly average results of chemical analyses, etc.*—Con.

SAMPLING STATION 475.—OHIO RIVER IMMEDIATELY BELOW CINCINNATI

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	163,400	11	10.3	46	208	7.3	9.27	83.1	2.91	8,267,710	2,557,670
December	127,500	11	2.6	47	93	7.4	12.88	94.5	2.64	8,887,680	1,817,040
1930											
January	205,500	10	2.3	42	160	7.4	12.26	92.6	2.30	13,726,000	2,652,180
February	138,900	10	4.2	45	170	7.4	12.80	98.0	2.54	9,588,960	1,908,780
March	210,400	11	6.4	36	141	7.3	11.64	94.2	2.25	13,224,900	2,568,800
April	100,400	13	12.3	35	65	7.4	10.08	93.2	2.28	5,487,980	1,238,190
May	35,600	12	20.3	44	22	7.4	8.48	93.0	2.57	1,620,200	494,060
June	23,000	13	23.7	70	5	......	7.02	87.7	2.69	952,980	358,940
July	6,990	13	27.0	49	5	......	4.05	50.2	3.49	151,880	128,000
August	2,990	13	26.2	54	5	......	1.72	20.6	3.73	26,410	70,990
September	4,830	13	23.7	66	3	......	2.30	25.7	3.54	57,390	93,390
October	3,360	14	16.1	74	5	......	2.94	29.6	3.98	53,340	72,270
November	5,570	10	9.7	72	5	......	7.58	66.4	5.45	227,980	162,990
December	12,610	14	3.0	54	7	......	12.20	90.5	5.09	830,750	346,600

AVERAGES

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
Year, 1930	62,580	......	14.6	55	48	......	7.78	70.1	3.57	3,826,340	841,130
November, 1929, to April, 1930	157,670	......	6.5	43	136	7.4	11.52	92.6	2.50	9,555,050	2,122,290
May to November, 1930	11,890	......	20.8	63	7	......	4.93	53.3	3.69	441,550	199,700

SAMPLING STATION 482.—OHIO RIVER 0.7 MILE BELOW DAM NO. 37 (FERNBANK)

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	163,700	11	9.6	44	264	7.3	9.46	82.9	3.11	8,380,130	2,749,180
December	127,700	12	2.5	49	112	7.5	12.82	93.9	2.90	8,840,420	1,792,910
1930											
January	205,900	12	2.9	49	123	7.3	12.46	92.3	2.35	13,876,010	2,612,870
February	130,100	12	4.3	51	214	7.4	12.66	97.2	2.01	9,524,460	2,260,930
March	210,800	12	6.4	37	178	7.3	11.71	94.8	2.26	13,329,730	2,572,600
April	100,600	13	12.5	41	65	7.4	10.02	93.5	2.33	5,443,260	1,266,750

AVERAGES

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
November, 1929, to April, 1930	157,970	......	6.4	45	159	7.4	11.53	92.5	2.61	9,890,000	2,209,04

TABLE No. 9.—*Summary of monthly average results of chemical analyses, etc.*—Con.

SAMPLING STATION 488.—OHIO RIVER JUST ABOVE THE GREAT MIAMI RIVER

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	164,000	8	9.1	46	221	7.4	9.78	84.6	2.36	8,661,170	2,090,220
December	137,900	5	4.6	47	63	7.4	12.92	98.9	2.15	8,920,220	1,484,930
1930											
January	208,200	4	5.5	51	200	7.4	12.08	95.4	1.96	13,428,670	2,171,290
February	138,300	7	5.4	40	139	7.4	12.46	98.3	2.10	9,272,660	1,579,680
March	211,100	16	6.4	36	176	7.3	11.56	93.5	1.77	13,166,310	2,017,690
April	100,800	11	11.6	30	61	7.4	10.06	93.0	1.98	5,475,980	1,077,780
May	35,700	9	19.6	46	17	7.4	8.11	88.1	1.89	1,563,450	364,380
June	28,100	9	23.6	54	5	......	7.08	82.4	2.66	863,100	324,300
July	8,960	12	25.8	51	5	......	6.36	77.1	3.12	298,690	117,090
August	3,960	11	26.4	55	7	......	5.36	64.5	3.22	113,750	68,260
September	4,830	10	23.1	72	2	......	4.28	49.4	2.24	112,080	58,670
October	3,370	11	15.7	79	3	......	4.28	42.8	2.34	77,890	42,580
November	5,890	8	10.5	73	5	......	6.75	60.2	2.61	208,750	84,830
December	12,650	9	5.6	63	7	......	11.19	88.8	4.01	764,300	273,930
AVERAGES											
Year, 1930	62,800	......	14.9	58	52	......	8.30	77.7	2.51	3,763,390	682,540
November, 1929, to April, 1930	158,230	......	7.1	44	142	7.4	11.47	94.0	2.06	9,837,980	1,736,820
May to November, 1930	11,920	......	20.6	66	6	......	6.05	66.4	2.61	456,110	152,890

SAMPLING STATION—GREAT MIAMI RIVER, AT MOUTH IN MIDSTREAM

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	4,820	9	7.7	196	122	7.9	9.55	79.8	4.11	248,570	106,980
December	8,730	5	5.4	185	136	7.9	12.05	95.1	2.84	568,060	133,880
1930											
January	26,800	4	4.5	139	306	7.7	12.35	95.3	2.59	1,787,290	374,830
February	10,670	7	5.4	213	270	8.0	11.72	92.5	3.58	675,280	206,270
March	6,850	10	6.3	226	80	8.1	11.34	91.5	2.74	419,470	101,350
April	3,570	11	12.4	227	78	8.1	9.60	90.2	3.31	186,800	63,810
May	1,670	9	20.7	242	48	8.1	8.78	97.1	4.92	79,180	44,370
June	1,260	9	24.6	405	20	......	9.02	106.9	5.66	61,370	38,510
July	733	12	25.3	197	15	......	7.68	92.2	5.53	30,400	21,860
August	662	11	22.6	198	28	......	6.75	78.6	4.63	24,880	17,060
September	678	10	21.3	198	25	......	7.10	79.4	3.61	33,660	14,270
October	748	11	14.4	235	15	......	8.01	77.9	2.40	32,350	9,690
November	686	8	9.5	228	15	......	8.11	70.8	2.95	30,130	10,960
December	755	9	4.0	235	5	......	10.47	79.7	4.04	42,690	16,470
AVERAGES											
Year, 1930	4,610	......	14.3	229	73	......	9.23	87.7	3.78	283,620	76,620
November, 1929, to April, 1930	10,240	......	7.0	198	161	8.0	11.12	90.7	3.20	647,580	104,520
May to November, 1930	951	......	19.9	243	24	......	7.92	86.1	4.16	41,710	22,390

TABLE No. 9.—*Summary of monthly average results of chemical analyses, etc.*—Con.

SAMPLING STATION 492.—OHIO RIVER 2.6 MILES BELOW THE MOUTH OF THE GREAT MIAMI RIVER

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20°C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	168,820	9	9.6	61	220	7.1	9.09	84.5	2.60	8,866,280	2,269,020
December	195,700	5	4.6	47	61	7.3	12.91	99.5	1.71	9,838,060	1,282,280
1930											
January	235,000	4	5.3	61	232	7.4	12.95	94.9	2.49	16,161,310	3,284,680
February	148,980	7	4.9	49	158	7.3	12.41	96.7	2.07	10,046,490	1,675,880
March	216,080	10	6.0	38	188	7.3	11.88	92.5	1.90	13,681,980	2,289,080
April	104,380	11	11.7	40	76	7.4	10.66	93.3	1.96	5,689,380	1,088,380
May	27,460	9	19.7	75	19	7.5	8.33	90.2	2.38	1,230,210	469,080
June	26,080	9	26.6	112	5	......	7.80	97.5	2.98	990,020	378,880
July	7,880	12	25.8	73	7	......	7.17	88.9	3.41	307,300	146,570
August	4,610	11	25.4	77	7	......	6.41	77.1	3.63	159,370	90,270
September	5,730	10	22.9	88	5	......	4.92	55.7	2.48	152,540	76,760
October	4,120	11	15.6	102	5	......	5.22	52.0	2.21	116,130	49,170
November	6,280	8	10.5	86	7	......	6.97	61.8	2.87	234,070	97,180
December	15,400	9	5.6	93	7	......	11.05	87.6	3.81	790,880	275,080
AVERAGES											
Year, 1930	67,400	......	14.7	73	58	......	8.64	81.4	2.67	4,077,580	831,440
November, 1929, to April, 1930	168,450	......	7.0	49	155	7.3	11.44	93.5	2.15	10,472,370	2,084,880
May to November, 1930	12,000	......	20.5	87	8	......	6.64	73.2	2.81	518,770	186,840

SAMPLING STATION 503.—OHIO RIVER JUST ABOVE RISING SUN, IND., AND 1.7 MILES BELOW DAM NO. 38

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20°C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	170,250	11	9.3	55	230	7.3	9.47	82.3	2.83	8,708,690	3,391,810
December	137,800	9	3.3	50	95	7.5	12.82	95.9	2.67	9,520,620	1,986,850
1930											
January	234,990	......	......	......	......	......	......	......	......	......	......
February	151,150	9	5.6	61	338	7.5	12.30	97.2	2.46	10,020,420	2,023,880
March	219,800	11	6.3	42	306	7.3	11.68	94.1	2.44	13,827,620	2,886,080
April	105,280	12	11.3	46	98	7.5	9.88	89.8	2.26	5,612,620	1,286,220
May	37,780	11	19.8	58	22	7.6	8.82	93.5	2.47	1,734,300	502,840
June	26,660	12	26.0	112	5	......	8.44	100.1	2.28	1,184,450	486,720
July	7,740	10	28.0	69	7	......	7.88	93.2	3.49	316,810	145,870
August	4,650	12	26.0	79	10	......	7.28	88.9	3.85	182,900	95,670
September	5,780	12	22.6	91	7	......	6.90	78.9	2.49	215,380	77,720
October	4,160	13	15.2	108	5	......	7.60	76.1	2.60	172,750	68,430
November	6,280	12	9.0	97	7	......	8.69	73.0	2.33	307,040	78,280
December	13,800	11	3.9	73	5	......	11.86	90.1	4.94	884,580	380,130
AVERAGES											
Year, 1930	67,990	......	15.3	76	52	......	9.60	82.4	2.90	3,123,820	724,880
November, 1929, to April, 1930	169,850	......	7.2	53	168	7.4	9.35	91.9	2.12	7,947,880	1,708,910
May to November, 1930	12,990	......	20.3	87	9	......	7.80	86.0	3.94	579,100	159,890

TABLE No. 9.—*Summary of monthly average results of chemical analyses, etc.*—Con.

SAMPLING STATION 535.—OHIO RIVER JUST ABOVE VEVAY, IND., AND 5.4 MILES BELOW DAM No. 39

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1929											
November	170,960	10	9.9	46	206	7.4	9.08	80.0	2.68	8,379,570	1,873,410
December	128,400	9	3.8	56	107	7.6	12.90	97.0	2.39	9,584,210	1,711,450
1930											
January	236,000	......	......	......	......	......	......	......	......	......	......
February	151,800	8	4.4	61	284	7.4	12.23	97.3	2.10	10,098,950	1,795,190
March	229,800	12	6.5	46	209	7.4	11.42	92.7	1.71	13,616,280	2,088,870
April	108,760	12	11.7	49	76	7.5	9.98	91.1	1.64	5,887,850	968,080
May	37,900	11	20.0	39	21	7.6	8.48	91.9	1.78	1,728,280	364,380
June	24,700	12	23.5	118	5	......	8.38	97.2	2.66	1,115,060	357,460
July	7,760	11	26.1	64	5	......	7.66	93.2	2.68	321,380	107,550
August	4,670	12	25.9	78	10	......	7.18	85.7	2.35	181,070	58,240
September	5,800	12	22.7	89	7	......	7.86	88.9	2.16	237,410	67,650
October	4,180	13	15.0	98	5	......	8.84	85.1	1.88	195,030	42,440
November	6,260	12	9.8	97	7	......	9.81	88.2	2.24	328,910	80,360
December	13,600	12	4.1	77	5	......	11.62	88.7	2.31	853,370	169,650

AVERAGES

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
Year 1930	66,270	......	15.4	78	53	......	9.36	90.5	2.13	3,122,600	545,880
November, 1929 to April, 1930	170,600	......	7.5	5[illegible]	166	7.5	9.26	91.6	1.64	7,888,150	1,392,500
May to November 1930	13,060	......	20.3	86	9	......	8.24	89.5	2.23	587,450	153,710

SAMPLING STATION—KENTUCKY RIVER, AT MOUTH, CARROLLTON, KY.

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1930											
June	285	3	26.7	......	......	7.9	8.44	104.0	5.20	12,990	8,140
July	153	10	28.2	69	6	7.9	6.37	77.8	2.73	5,260	2,680
August	188	13	28.5	60	7	7.8	5.98	68.9	2.71	6,030	2,750
September	115	12	22.3	81	14	7.7	6.21	70.7	2.30	3,860	1,480
October	125	13	16.3	87	7	7.7	7.21	72.9	2.25	4,870	1,520
November	202	11	9.4	86	5	7.6	7.90	68.8	2.20	8,620	2,400
December	210	13	3.7	98	6	7.7	10.66	90.5	2.50	17,940	4,190

AVERAGES

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
June to November, 1930	178	......	20.7	79	8	7.7	7.01	77.2	3.10	6,940	3,280

TABLE No. 9.—*Summary of monthly average results of chemical analyses, etc.*—Con.

SAMPLING STATION 548.—OHIO RIVER AT BROOKSBURG, IND., 4.6 MILES BELOW MOUTH OF KENTUCKY RIVER

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1930											
June	35,000	3	23.0	......	......	7.9	8.14	97.1	3.97	1,088,000	335,000
July	7,940	9	28.1	83	8	7.8	7.60	94.2	2.91	329,720	120,000
August	4,880	12	28.1	81	7	7.7	7.30	93.4	2.26	190,900	88,700
September	5,000	12	23.0	80	7	7.7	7.78	92.6	2.48	209,710	79,200
October	4,310	11	14.0	91	5	7.8	8.98	88.7	2.10	207,040	40,800
November	6,570	9	9.0	95	4	7.7	10.00	88.3	2.07	354,700	72,440
December	15,900	10	3.3	74	5	7.8	12.21	91.3	2.00	916,400	180,800

AVERAGES

June to November, 1930	9,100	......	20.0	78	6	7.8	8.22	90.9	2.60	405,600	153,720

SAMPLING STATION 598.—OHIO RIVER IMMEDIATELY ABOVE LOUISVILLE, KY., OPPOSITE WATERWORKS INTAKE

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	5-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1930											
May	41,700	12	20.1	88	18	......	9.00	98.3	4.61	3,038,010	887,730
June	25,300	12	24.0	88	10	7.8	8.94	104.8	3.10	1,221,300	435,000
July	8,040	12	27.7	84	2	7.7	6.90	88.1	3.60	297,000	100,210
August	4,930	12	27.4	88	7	7.7	6.60	83.1	2.40	176,940	96,150
September	5,030	12	26.0	75	5	7.8	6.65	79.4	1.98	215,400	68,300
October	4,380	11	16.8	90	5	7.8	7.75	82.1	1.48	182,470	37,070
November	6,630	8	11.3	106	3	7.8	10.24	94.0	1.87	371,310	68,200
December	14,100	13	5.0	87	4	7.8	12.46	97.8	1.76	947,940	124,010
1931											
January	21,600	10	1.9	62	7	7.1	12.19	87.8	1.29	1,421,040	180,470
February	58,300	10	4.0	41	40	7.4	11.60	88.4	1.25	3,600,200	390,900
March	73,800	11	4.9	37	80	7.3	11.27	87.9	1.26	4,600,470	542,900
April	228,100	13	8.6	22	300	7.0	9.18	78.8	2.15	11,280,220	2,626,000
May	125,800	11	16.3	34	38	7.3	8.61	87.0	1.04	5,830,000	790,410

AVERAGES

May, 1930, to April, 1931	41,420	......	14.9	64	31	7.7	9.27	88.7	2.06	2,322,400	457,570
May to November, 1930	13,550	......	22.0	73	7	7.8	8.08	89.7	2.42	641,720	208,400
November, 1930, to April, 1931	67,700	......	6.0	61	56	7.3	11.00	88.4	1.55	3,728,190	690,620

TABLE No. 9.—*Summary of monthly average results of chemical analyses, etc.*—Con.

SAMPLING STATION 605.—OHIO RIVER OPPOSITE NEW ALBANY WATERWORKS ABOUT 1 MILE BELOW DAM No. 41

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	3-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1930											
May [1]	41,700	13	21.4	59	23	7.8	9.20	104.0	4.36	2,080,670	898,380
June [1]	25,300	13	24.5	61	7	7.9	9.38	110.0	5.19	1,267,930	709,090
July [1]	8,040	12	27.8	63	5	7.7	7.08	89.2	6.02	307,300	251,360
August	4,930	11	27.5	63	4	7.8	6.78	84.8	2.96	180,130	105,880
September	6,000	13	25.1	77	10	7.8	6.43	78.8	2.57	275,070	128,380
October	4,380	11	18.4	87	6	7.8	7.42	78.4	2.01	174,780	70,970
November	5,680	9	10.9	103	5	7.8	9.91	88.2	2.35	354,570	94,280
December	14,100	10	[illegible]	98	7	7.7	12.31	97.1	2.09	937,390	159,190
1931											
January	21,600	12	1.9	68	8	7.2	12.47	89.8	1.90	1,454,500	290,950
February	58,500	10	2.9	55	35	7.3	11.30	88.4	1.79	3,394,940	565,480
March	79,900	11	4.4	41	60	7.2	11.64	89.4	1.87	5,015,910	906,930
April	226,100	11	9.1	25	312	7.3	9.47	82.0	2.95	11,262,200	3,728,870
May	125,800	11	16.3	36	107	7.2	8.14	82.6	2.23	5,516,480	1,511,270
AVERAGES											
May, 1930, to April, 1931	41,420	......	16.0	68	40	7.6	9.45	89.8	3.27	2,282,380	650,350
May to November, 1930	13,880	......	22.2	75	9	7.8	8.02	90.3	4.10	654,930	334,270
November, 1930, to April, 1931	67,790	......	5.0	67	71	7.4	11.20	88.0	2.16	3,830,130	924,770

[1] Sample from north sampling section only.

SAMPLING STATION 624.—OHIO RIVER AT KOSMOSDALE, KY., 20 MILES BELOW DAM No. 41

Month	Mean monthly discharge, sec.-ft.	Number of samples collected	Mean water temperature, °C.	Alkalinity, p. p. m.	Turbidity, p. p. m.	Hydrogen-ion concentration (pH)	Dissolved oxygen			Dissolved oxygen and oxygen demand expressed as the daily average in pounds	
							Initial, p. p. m.	Initial as per cent saturation	3-day loss at 20° C., p. p. m.	Dissolved oxygen	Oxygen demand
1930											
May	41,700	12	20.3	62	25	......	8.66	96.2	2.94	1,904,880	630,510
June	25,800	12	23.8	63	7	7.9	8.76	102.3	2.60	1,196,790	255,210
July	8,040	13	27.1	63	5	7.8	7.34	91.1	1.87	310,670	81,190
August	4,900	13	27.5	61	5	7.7	6.97	87.2	2.26	186,180	59,510
September	6,000	13	24.8	77	6	7.8	6.88	78.2	1.57	213,190	60,880
October	4,380	13	18.2	86	5	7.8	7.33	78.1	1.74	170,220	46,970
November	5,680	11	11.3	103	3	7.7	9.00	82.6	1.79	336,420	64,380
December	14,100	12	5.0	94	5	7.7	12.04	94.1	2.44	916,720	185,780
1931											
January	21,650	10	1.8	64	7	7.1	12.30	88.3	2.02	1,434,670	235,610
February	58,800	10	2.9	42	45	7.4	10.86	82.7	1.63	3,436,900	514,920
March	79,800	12	4.3	40	80	7.0	11.17	85.4	1.25	4,812,250	530,660
April	226,100	13	9.1	36	375	7.0	9.14	79.2	2.81	11,180,340	3,430,840
May	120,800	11	16.0	35	75	7.2	8.61	86.6	1.35	5,635,000	901,340
AVERAGES											
May, 1930, to April, 1931	41,420	......	14.5	66	47	7.5	9.18	86.9	2.10	2,177,180	517,200
May to November, 1930	13,880	......	21.9	74	8	7.8	7.61	87.5	2.14	629,880	185,880
November, 1930, to April, 1931	67,790	......	6.0	62	86	7.3	10.77	86.4	1.99	3,661,280	828,350

PRECISION OF THE ANALYTICAL RESULTS

Since the purpose of the chemical analyses is to indicate the direction and extent of the changes taking place in the watercourse, it is of importance to ascertain the precision of the chemical results in order to judge whether observed differences are significant of actual changes taking place in the stream or are attributable merely to chance variations in the observations.

The errors to which the chemical observations may be subject are complex, but the several individual errors influencing the accuracy of the final results may in general be grouped as follows: (*a*) Errors of the actual analysis of the sample in the laboratory, (*b*) errors involved in the assumption that samples collected from one or more points on the cross section of a stream are representative of the entire volume of the water passing that section, (*c*) errors due to the assumption that the water passing a sampling station at the time of sample collection is representative of conditions during the interval of time which the sample is taken to represent, and (*d*) errors introduced when using the discharge estimates with the laboratory results to express the various constituents in terms of absolute amounts carried by the water at the various sampling points.

As a result of the complexity of the several errors, the net probable error of a single determination, or of a series of determinations, is not deducible with any degree of certainty, but it may be approximated by studying the observed differences between values independently obtained, which if precisely determined would have been equal.

The data available for such a study are limited, there being but one set of observations which may properly be compared on the assumption that the differences observed are due almost entirely to errors in the observations. These data are from sampling stations 488 and 492, on the Ohio River just above and below, respectively, the mouth of the Great Miami River. The velocity of flow through this 4 miles of river section is usually comparatively high, but decreases considerably at times of pool stage. During the six months' period of open channel, November, 1929 to April, 1930, inclusive, the mean monthly time of flow between stations 488 and 492 was 3½ hours or less, increasing to a maximum of 25 hours in October, 1930, at a time of pool stage when the mean monthly discharge was lowest. Within this section of the river there are no sources of pollution which would affect in any way the condition of a stream as large as the Ohio River.[10]

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[10] A second series of observations, limited to a 7-month period, June to December, 1930, inclusive, is available from the data at sampling stations 536 and 546, on the main stream, above and below the Kentucky River, and from the station near the mouth of this tributary. During the 7-month period for which data are available, the river was continuously at pool stage and the time of flow through the 12-mile section varied between 27 and 160 hours. With these relatively long times of flow, normal changes in the condition of the river, due to the operation of natural purification agencies, might be attributed to errors in the observations. The results of the calculations using these latter data have been included in the following discussion to give additional information and to serve as a rough check on the results of the calculations using the data from the upper section of the stream near the Great Miami River.

The actual amount of any constituent in the main stream, below the confluence of a tributary, should be equal to the amount contributed by the tributary, plus the amount in the main stream above its mouth. A comparison of the amounts in the main stream below the Great Miami River, with the sum of the amounts in the tributary and in the main stream above the Great Miami River, is presented in Table No. 10, which shows, for each of four determinations, dissolved oxygen, oxygen demand, alkalinity and turbidity, the following:

(*a*) Monthly mean amounts carried by the Ohio River below the Great Miami River, station 492.

(*b*) The sum of the monthly mean amounts carried by the Great Miami River and the Ohio River at station 488, above the confluence of the tributary.

(*c*) The mean of a and b $\left(\frac{a+b}{2}\right)$.

(d_1) The difference $(a-b)$, with positive or negative sign according as a is greater or less than b.

(d_2) The difference $(a-b)$ expressed as percentages of the mean

$$100\times(a-b)\div\left(\frac{a+b}{2}\right)$$

In Table No. 10 the individual deviations d_2 vary from 0.03 to 36.6 per cent, the average deviations of each of the four constituents from ±3.2 to ±11.3 per cent. In Table No. 11 all of the deviations in each series have been assembled according to sign and magnitude without distinction as to the determinations from which they were derived.

Table No. 10.—*Amounts of various chemical constituents, expressed as the daily average in pounds, carried by the Ohio River at station 492, compared with the sum of the amounts carried by the Great Miami River and the Ohio River at station 488*

Month	Dissolved oxygen					Oxygen demand				
	Pounds of dissolved oxygen, station 492 (a)	Pounds of dissolved oxygen, station 488 plus Great Miami (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d_1)	Per cent $\frac{d_1\times 100}{c}$ (d_2)	Pounds of oxygen demand, station 492 (a)	Pounds of oxygen demand, station 488 plus Great Miami (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d_1)	Per cent $\frac{d_1\times 100}{c}$ (d_2)
1929										
November	8, 805, 280	8, 909, 740	8, 857, 510	−104, 460	−1. 18	2, 369, 960	2, 197, 000	2, 283, 480	+172, 960	+7. 57
December	9, 529, 900	9, 491, 390	9, 510, 650	+38, 510	+0. 40	1, 262, 290	1, 618, 800	1, 440, 550	−356, 510	−24. 75
1930										
January	15, 161, 310	15, 215, 860	15, 188, 590	−54, 550	−0. 36	3, 384, 560	2, 546, 110	2, 965, 340	+838, 450	+28. 27
February	10, 045, 400	10, 047, 940	10, 046, 670	−2, 540	−0. 03	1, 675, 580	1, 785, 930	1, 730, 760	−110, 350	−6. 38
March	13, 631, 980	13, 585, 780	13, 608, 880	+46, 200	+0. 34	2, 236, 680	2, 119, 040	2, 177, 860	+117, 640	+5. 40
April	5, 660, 360	5, 662, 660	5, 661, 510	−2, 300	−0. 04	1, 098, 280	1, 141, 560	1, 119, 920	−43, 280	−3. 87
May	1, 680, 310	1, 642, 630	1, 661, 470	+37, 680	+2. 27	480, 660	408, 720	444, 690	+71, 940	+16. 18
June	990, 830	944, 530	967, 680	+46, 300	+4. 79	376, 830	372, 810	374, 820	+4, 020	+1. 07
July	297, 350	269, 090	283, 220	+28, 260	+9. 98	145, 570	138, 980	142, 280	+6, 590	+4. 63
August	159, 570	138, 610	149, 090	+20, 960	+14. 06	90, 370	85, 380	87, 880	+4, 990	+5. 68
September	152, 540	145, 750	149, 150	+6, 790	+4. 55	76, 740	72, 940	74, 840	+3, 800	+5. 08
October	116, 130	110, 240	113, 190	+5, 890	+5. 20	49, 170	52, 270	50, 720	−3, 100	−6. 11
November	234, 670	233, 890	234, 280	+780	+0. 33	87, 150	95, 790	91, 470	−8, 640	−9. 45
December	799, 580	807, 080	803, 330	−7, 500	−0. 93	275, 690	290, 390	283, 040	−14, 700	−5. 19
Mean					±3. 2					±9. 3
					Per cent					*Per cent*
Standard deviation of difference δ_{a-b}					4. 91					12. 10
Probable error of differences ϵ_{a-b}					±3. 31					±8. 16
Probable error of monthly mean $\epsilon_a=\epsilon_b$					±2. 34					±5. 77

TABLE No. 10.—*Amounts of various chemical constituents, expressed as the daily average in pounds, carried by the Ohio River at station 492, compared with the sum of the amounts carried by the Great Miami River and the Ohio River at station 488*—Continued

Month	Turbidity					Alkalinity				
	Pounds of suspended matter, station 492 (a)	Pounds of suspended matter, station 488 plus Great Miami (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d_1)	Per cent $\frac{d_1\times100}{c}$ (d_2)	Pounds of alkalinity, station 492 (a)	Pounds of alkalinity, station 488 plus Great Miami (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d_1)	Per cent $\frac{d_1\times100}{c}$ (d_2)
1929										
November	207,826,560	198,893,020	203,359,790	+8,933,540	+4.4	55,002,720	47,010,280	51,006,500	+7,992,440	+15.5
December	45,028,980	49,326,520	47,177,750	−4,297,540	−9.1	34,694,480	41,182,280	37,938,380	−6,487,800	−17.1
1930										
January	279,320,400	266,980,320	273,150,360	+12,340,080	+4.5	70,750,200	70,903,000	70,826,600	−152,800	−0.2
February	125,466,300	120,115,440	122,790,870	+5,350,860	+4.4	39,663,540	46,874,750	43,269,150	−7,211,210	−16.7
March	217,782,000	202,478,940	210,130,470	+15,303,060	+7.3	42,379,200	49,397,580	45,888,390	−7,018,380	−15.3
April	42,804,720	34,707,200	38,755,960	+8,097,520	+20.9	22,528,800	25,604,500	24,066,650	−3,075,700	−12.8
May	3,837,240	3,710,120	3,773,680	+127,120	+3.4	15,147,000	11,050,240	13,098,620	+4,096,760	+31.3
June	658,800	759,780	709,290	−100,980	−14.2	14,757,120	13,235,780	13,996,450	+1,521,340	+10.9
July	290,300	247,020	268,660	+43,280	+16.1	2,955,980	2,663,760	2,809,870	+292,220	+10.3
August	174,260	252,430	213,350	−78,170	−36.6	1,817,260	1,902,390	1,859,820	−85,130	−4.6
September	154,710	170,910	162,810	−16,200	−9.9	2,722,900	2,824,400	2,773,650	−101,500	−3.7
October	111,240	115,180	113,210	−3,940	−3.5	2,268,300	2,385,810	2,327,050	−117,510	−5.0
November	237,380	206,660	222,020	+30,720	+13.8	2,984,240	3,050,600	3,017,420	−66,360	−2.2
December	506,520	498,560	502,540	+7,960	+1.6	5,933,520	5,261,620	5,597,570	+671,900	+12.0
Mean					±10.7					±11.3
					Per cent					*Per cent*
Standard deviation of difference δ_{a-b}					14.01					12.65
Probable error of differences e_{a-b}					±9.45					±8.53
Probable error of monthly mean $e_a=e_b$					±6.68					±6.03

TABLE No. 11.—*Distribution of the deviations* (d_2) *of various constituents as shown in Table No. 10*

[Per cent of mean]

Class	Frequency			Class	Frequency		
	+	−	Total		+	−	Total
0 to 4.9 per cent	13	11	24	25 to 29.9 per cent	1	0	1
5 to 9.9 per cent	7	7	14	30 to 34.9 per cent	1	0	1
10 to 14.9 per cent	5	2	7	35 to 39.9 per cent	0	1	1
15 to 19.9 per cent	3	3	6				
20 to 24.9 per cent	1	1	2	Total	31	25	56

The summation of these data shows that, from above to below the Great Miami River, the positive and negative deviations are nearly balanced and that in this instance the errors, including analysis, sampling and discharge, are compensatory.

The "probable error"[11] of the observation is the range within which one-half of the errors would be expected to fall with a large number of observations available.

The probable error and other related data derived from the observed deviations d_2 distributed as shown in Table No. 11 are:

	Per cent
Standard deviation of differences δ_{a-b}	11. 80
Probable error of differences ϵ_{a-b}	±7. 96
Probable error of monthly mean $\epsilon_a = \epsilon_b$	±5. 63

The significance of the probable errors, on the basis of the accepted mathematical theories upon which they are based, is that the difference between the values of the monthly means a and b, which in the absence of any error, should equal zero, may vary from ±7.96 per cent of their mean, provided the differences are due entirely to chance or random errors. Stated in another manner: In any sufficiently large series of observations half of the differences $(a-b)$ would fall within the range ±7.96 per cent. The probable error of the separate values of a and b signifies that an observed monthly mean at sta-

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[11] The probable error is computed by the general formula,

$$\epsilon = 0.67449 \times \delta$$

in which ϵ represents the probable error and δ the standard deviation of the observed distribution. The error thus computed is the error of the difference between 2 monthly means a and b, expressed as a percentage of their mean; and bears to the separate errors of a and b, respectively, the relation

$$\epsilon_{a-b} = \sqrt{\epsilon_a^2 + \epsilon_b^2}$$

in which ϵ_a amd ϵ_b are equal to the probable error of a and b respectively, and ϵ_{a-b} to the probable error of the differences. If it is assumed, in this case, that the errors of a and b are equal, then,

$$\epsilon_{a-b} = \sqrt{\epsilon_a^2 + \epsilon_b^2} = \sqrt{2\epsilon_a^2} = \epsilon_a\sqrt{2}$$

and since ϵ_a is assumed equal to ϵ_b, then

$$= \epsilon_b = \frac{\epsilon_{a-b}}{\sqrt{2}}$$

tion 492, or at station 488 and the Great Miami River, may differ from the true value by ±5.63 per cent.[12]

Calculations made with the data of the 1914–1916 survey, using however, with the exception of the alkalinity determinations, chemical constituents entirely different from those taken for the present calculation, give values derived from the observed deviations, as follows:

	Per cent
Standard deviation of differences δ_{a-b}	18.45
Probable error of differences ϵ_{a-b}	±12.45
Probable error of monthly mean $\epsilon_a=\epsilon_b$	±8.80

A comparison of the 1929–30 results with those of 1914–1916 indicates that the range of error for the particular chemical determinations used in the 1929–30 calculations (dissolved oxygen, oxygen demand, alkalinity and turbidity) was somewhat less than the range in the 1914–1916 calculations—using hardness, alkalinity, chlorine, organic nitrogen, mineral nitrogen, and oxygen consumed. A direct comparison of the precision of the analytical results of the past and present investigations is available by comparing turbidity determinations made at the same stations in both investigations, namely, above and below the Great Miami River and on the tributary. These data are summarized as follows and indicate probable errors almost identical from the two sets of observations:

Source of data	Standard deviation of differences	Probable error of differences	Probable error of monthly mean
1914–1916	13.91	±9.38	±6.63
1929–30	14.01	±9.45	±6.67

In Table No. 12 there have been assembled from the results of the dissolved oxygen, oxygen demand, alkalinity and turbidity determinations, in the vicinity of the Great Miami River, the standard deviation of the differences, probable error of the differences, and the probable error of the monthly mean for each of the separate chemical constituents.

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[12] A similar computation using the less extensive results, for the 7-month period June to December, 1930, above and below the Kentucky River, gives the following standard deviations of the differences and probable error of the differences and monthly mean:

	Per cent
Standard deviation of differences δ_{a-b}	16.33
Probable error of differences ϵ_{a-b}	±11.01
Probable error of monthly mean $\epsilon_a=\epsilon_b$	±7.77

Because of the less extensive series of observations used in this calculation, greater probable errors would be expected and they so appear in the results. The individual deviations d_i vary from 0.3 to 53.7 per cent with average deviations for each of the 4 constituents, dissolved oxygen, oxygen demand, alkalinity and turbidity, varying from ±3.1 to ±15.3 per cent. Deviations of the dissolved oxygen results have in the majority of cases positive signs, suggesting a constant tendency during pool stages toward greater amounts of dissolved oxygen at the lower station. In the case of the alkalinity and turbidity the differences, without exception, are of negative sign, suggesting a constant tendency toward lower turbidities and alkalinities at station 548 at times of pool stage. Individual deviations in the case of the oxygen demand are equally distributed. When the limited data available are considered, these results are in fair agreement with the results from the stations in the vicinity of the Great Miami River.

TABLE No. 12.—*Summary of the precision of various chemical determinations, using data at sampling stations on the Ohio River above and below the Great Miami River*

(Per cent)

Determination	Number of observations	Standard deviation of differences δ_{a-b}	Probable error of differences ϵ_{a-b}	Probable error of monthly mean $\epsilon_a=\epsilon_b$
Dissolved oxygen	14	4.91	±3.31	±2.34
Oxygen demand	14	12.10	±8.16	±5.77
Alkalinity	14	13.68	±9.23	±6.53
Turbidity	14	14.01	±9.45	±6.68
Combined	56	11.80	±7.96	±5.63

The data of Table No. 12 indicate considerable variation in probable errors of the individual constituents, the least error occurring in the dissolved oxygen results, the errors in the alkalinity and turbidity determinations appearing to be greatest, and approximately the same, with the error of the oxygen demand determination somewhat greater than that of the dissolved oxygen but less than the errors of the alkalinity and turbidity determinations.[13]

Considering the small number of observations, the limited number of chemical determinations, variations in the number of samples comprising the monthly averages, and that certain assumptions are probably not exactly true, the computed probable errors (Table No. 12) should be taken as an indication rather than a measure of the probable variation due to the combined errors of analysis, sampling, and discharge. The indicated errors do however give some reasonable and more or less definite idea of the precision of the analytical data, emphasizing the fact that variations within the range of 3 to 10 per cent are probably not sufficiently accurate to be of significance. On the other hand, if it is assumed that in order to be of significance the percentage changes in the various chemical constituents should be, say, three times the probable error of the differences, then changes in

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[13] Individual deviations of the differences, probable error of the differences, and probable error of the monthly mean for the dissolved oxygen, oxygen demand, alkalinity, and turbidity calculated for stations 535, 546 and the Kentucky River are as follows:

Determination	Per cent		
	Standard deviation of differences δ_{a-b}	Probable error of differences ϵ_{a-b}	Probable error of monthly mean $\epsilon_a=\epsilon_b$
Dissolved oxygen	3.33	±2.25	±1.59
Oxygen demand	17.51	±11.81	±8.35
Alkalinity	10.43	±7.03	±4.97
Turbidity	26.01	±17.54	±12.40

These calculations suggest somewhat smaller probable errors in the dissolved oxygen and alkalinity results and greater errors in the oxygen demand and turbidity determinations than the errors calculated from the more extensive data from the vicinity of the Great Miami River.

the monthly average amounts of dissolved oxygen should be in excess of about ±10 per cent, of the oxygen demand in excess of about ±25 per cent and of the alkalinity and turbidity in excess of about ±30 per cent.

The assumption of a probable error of from 3 to 10 per cent in monthly means is further justified by the general agreement as to the direction and extent between observed and expected changes between consecutive sampling stations. As an example, the oxygen balance would be expected to decrease past Cincinnati due to the addition of industrial wastes and the sewage from a population of about 600,000. If it is assumed that the industrial waste pollution, surface wash, and other sources of pollution are equivalent to 2.5 times the actual sewered population, the daily contribution of oxygen demand discharged into the river would be about 344,000 pounds. The average yearly concentration of dissolved oxygen and oxygen demand of 10.34 and 1.65 parts per million, respectively, above Cincinnati give an average yearly oxygen balance of 8.67 parts per million. When stream flows are approximately 75,000 second-feet or greater at Cincinnati, the change in oxygen balance would be 10 per cent or less, smaller than the probable error of the monthly differences, and at such times the indicated change in oxygen balance from above to below Cincinnati may show an increase, an irrational result obviously due to errors in observation. On the other hand, stream flows of about 37,000 second-feet or less give indicated increases in oxygen balance 20 per cent or greater and under such conditions the changes from above to below Cincinnati are consistently uniform.

DISCUSSION OF THE CHEMICAL DETERMINATIONS

TEMPERATURE

Table No. 13 summarizes mean monthly water temperatures, in degrees centigrade, at each sampling station between Cincinnati and Louisville.

The lowest mean monthly temperature of the main river was 2.5° C. in December, 1929, the highest 27.7° C., in July, 1930. Minimum daily temperatures of 0° C. were observed in the main stream, at stations 461 and 475, and in the Little Miami River, during December, 1929. Maximum daily temperatures of 29° C. occurred in the main river at station 475, and in the Licking and Great Miami Rivers, during July, 1930.

Such slight variations as occur in the monthly mean temperatures would suggest somewhat lower temperatures in the Little Miami and Great Miami Rivers and somewhat higher temperatures in the Licking and Kentucky Rivers than those of the main river near their respective points of confluence.

Seasonal averages of temperature in the winter and spring period, November, 1929, to April, 1930, inclusive, between stations 461 and

535, varied from 6.4° C. to 7.5° C., indicating a maximum variation of 1.1° C. in the section under observation. In the summer and fall period, May to November, 1930, inclusive, seasonal averages of water temperature varied between 20.2° C. and 22.0° C., a difference of 1.8° C. The average winter temperature was 6.9° C., that of the summer period 20.7° C.

TABLE No. 13.—*Average monthly and seasonal temperatures, in degrees Centigrade, arranged by sampling stations and months*

Month	Mean monthly temperature at station														
	461	Little Miami	Licking	475	482	486	Great Miami	492	505	535	Kentucky	546	598	605	624
1929															
November	9.6	7.7	9.6	10.3	9.6	9.1	7.7	9.6	9.3	9.9	-----	-----	-----	-----	-----
December	2.5	3.1	2.9	2.6	2.5	4.6	5.4	4.6	3.3	3.8	-----	-----	-----	-----	-----
1930															
January	2.9	3.8	4.2	3.3	2.9	5.5	4.5	5.3	-----	-----	-----	-----	-----	-----	-----
February	4.1	5.4	6.5	4.2	4.3	5.4	5.4	4.9	5.6	5.4	-----	-----	-----	-----	-----
March	6.6	6.0	7.4	6.4	6.4	6.4	6.3	6.0	6.2	6.5	-----	-----	-----	-----	-----
April	11.6	12.5	13.8	12.3	12.5	11.6	12.4	11.7	11.3	11.7	-----	-----	-----	-----	-----
May	20.1	19.8	21.1	20.3	-----	19.9	20.7	19.7	19.8	20.0	-----	-----	20.1	21.4	20.3
June	22.9	22.1	24.6	23.7	-----	22.6	24.6	22.6	24.0	23.5	20.7	25.0	24.0	24.5	25.8
July	26.9	24.3	27.3	27.0	-----	25.8	25.3	26.8	26.0	26.1	26.2	26.4	27.7	27.8	27.1
August	26.4	23.4	25.2	26.2	-----	26.4	23.6	26.4	25.0	26.0	23.5	25.1	27.4	27.8	27.5
September	25.4	21.7	24.8	23.7	-----	23.1	21.3	22.9	22.6	22.7	22.3	23.0	26.0	26.1	24.8
October	16.1	13.8	15.9	16.1	-----	15.7	14.4	15.6	15.2	15.0	16.3	16.0	18.5	18.4	18.2
November	9.2	8.6	9.8	9.7	-----	10.5	9.5	10.5	9.0	9.8	9.4	9.0	11.2	10.9	11.3
December	2.8	1.5	3.7	3.0	-----	5.6	4.0	5.6	3.9	4.1	3.7	3.3	5.0	5.4	5.0
1931															
January	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.9	1.9	1.8
February	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	4.0	3.9	3.9
March	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	4.9	4.4	4.3
April	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	8.8	9.1	9.1
May	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	16.3	16.3	16.0
AVERAGES															
November, 1929, to April, 1930	6.4	6.4	7.4	6.5	6.4	7.1	7.0	7.0	7.2	7.5	-----	-----	-----	-----	-----
May to November, 1930	20.7	19.2	21.2	20.8	-----	20.6	19.9	20.5	20.2	20.3	20.7	20.8	22.0	22.2	21.9
November, 1930, to April, 1931	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	6.0	6.0	6.0

HYDROGEN-ION CONCENTRATION

Hydrogen-ion concentration determinations showed but little variation between main river stations, the mean monthly concentrations falling between 7.3 and 7.5. The Little Miami and Great Miami Rivers, entering from the northern portion of the watershed, had mean monthly hydrogen-ion concentrations of 8.0; somewhat higher than those of the main river, while the Licking and Kentucky Rivers entering from the southern portion of the watershed had concentrations of 7.8 and 7.7, respectively; somewhat lower than the northern tributaries, but still higher than the concentrations of the main river.

TURBIDITY

Observations of turbidity, as monthly averages in parts per million at all sampling stations, are summarized for the entire period of the investigation in Table No. 14.

TABLE No. 14.—*Average monthly and seasonal turbidity, parts per million, arranged by sampling stations and months*

Month	Mean monthly turbidity at station														
	461	Little Miami	Licking	475	482	488	Great Miami	492	498	535	Kentucky	546	586	605	624
1929															
November	177	303	167	208	264	221	122	226	236	206	-----	-----	-----	-----	-----
December	116	184	250	95	112	63	185	[illegible]	[illegible]	107	-----	-----	-----	-----	-----
1930															
January	132	138	218	140	123	200	208	232	-----	-----	-----	-----	-----	-----	-----
February	157	695	698	170	214	129	270	156	208	234	-----	-----	-----	-----	-----
March	173	87	71	141	176	176	80	185	205	209	-----	-----	-----	-----	-----
April	67	71	138	66	65	61	73	76	89	78	-----	-----	-----	-----	-----
May	19	24	114	22	-----	17	48	19	22	21	-----	-----	15	23	25
June	8	8	53	8	-----	8	20	8	8	8	-----	-----	10	7	7
July	8	8	26	8	-----	8	15	7	7	8	8	8	2	8	8
August	8	10	22	8	-----	7	26	7	10	10	7	7	7	8	8
September	7	70	130	3	-----	2	25	8	7	7	14	7	8	10	8
October	5	18	35	8	-----	3	15	5	5	8	7	5	5	6	5
November	8	15	29	5	-----	5	15	7	7	7	5	4	2	8	2
December	7	10	7	7	-----	7	8	7	5	5	6	5	4	7	5
1931															
January	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	7	8	7
February	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	40	35	45
March	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	80	6C	80
April	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	200	312	375
May	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	36	107	75
AVERAGES															
November, 1929, to April, 1930	135	218	250	138	180	143	161	155	163	166	-----	-----	-----	-----	-----
May to November, 1930	7	21	60	7	-----	6	24	8	9	9	8	6	7	9	8
November, 1930, to April, 1931	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	56	71	86

Average turbidities of the Little Miami and Licking Rivers are higher than those of the main stream in the vicinity of their points of confluence. Turbidities in the Kentucky River appear to exceed those of the Ohio River when the flow of the tributary is unobstructed by the navigation dams along its course, but at pool stages normal turbidities are reduced by sedimentation to practically the same as those of the Ohio River at its junction.

At times of unobstructed flow in the Ohio River, the higher turbidities in the tributaries have a tendency to increase that of the main stream in the section between Cincinnati and Louisville, but during periods of continuous pool stage the higher turbidities of the Little Miami and Licking Rivers produce but slight effect and at such times the turbidity of the main stream tends to decrease below Cincinnati.

Daily readings of turbidity were obtained during the 7-month period, November, 1929, to May, 1930, inclusive. In the months of November to April, inclusive, turbidities are representative of conditions during unobstructed flow in the river, and the month of May of turbidities at pool stage. Variations in daily turbidities at stations

461, 475, and 535, on the main stream, and at stations on the Little Miami, Licking, and Great Miami Rivers, are summarized in Table No. 15.

Table No. 15.—*Distribution of turbidities of individual samples from the Ohio, Little Miami, Licking, and Great Miami Rivers, during periods of unobstructed flow*

Turbidity range	Number of observations						Per cent of observations					
	Ohio station 461	Ohio station 475	Ohio station 535	Little Miami River	Licking River	Great Miami River	Ohio station 461	Ohio station 475	Ohio station 535	Little Miami River	Licking River	Great Miami River
0 to 25	0	2	3	12	4	11	0	3.0	5.9	25.0	8.3	25.0
26 to 50	8	10	7	19	13	16	17.4	15.2	13.7	39.6	27.1	36.5
51 to 100	15	21	16	5	8	5	32.6	31.8	31.4	10.4	16.6	11.3
101 to 250	18	27	16	2	12	5	39.1	40.9	31.4	4.2	25.0	11.3
251 to 500	5	6	7	5	5	2	10.9	9.1	13.7	10.4	10.4	4.6
501 to 1,000	0	0	2	3	3	5	0	0	3.9	6.2	6.3	11.3
1,001 to 2,500	0	0	0	2	3	0	0	0	0	4.2	6.3	0
Total	46	66	51	48	48	44	100	100	100	100	100	100

The data of Table No. 15 indicate that during periods of unobstructed flow in the main channel the usual range of turbidity is between 50 and 250 parts per million, but with the navigation dams raised, forming a succession of pools and permitting extensive sedimentation, the range of turbidity is reduced to between 0 and 25 parts per million. On the Little Miami and Great Miami Rivers, daily turbidities usually fall between 0 and 50 parts per million, while the range on the Licking River is higher, between 25 and 250 parts per million. The Little Miami and Licking Rivers, with less extensive watershed areas and more rapid run-off, have turbidities at times between 1,000 and 2,500 parts per million.

Differences in the turbidity observations during periods of unobstructed flow and at times of pool stage, indicate quite clearly that changes in turbidity are intimately related to the velocity of flow in the stream. The extremely low velocities through the pools during the spring and summer of 1930, when the river was continuously at pool stage, decreased turbidities to such an extent, throughout the entire system, that the indicated differences in amounts of turbidity at successive sampling stations fall within the range of the probable error of the observation and are of no significance in correlating the velocity of flow with decrease in turbidity.

ALKALINITY

Summaries of the alkalinity determinations, expressed in parts per million, are presented in Table No. 16 as monthly and seasonal averages at each of the sampling stations between Cincinnati and Louisville.

TABLE No. 16.—*Average monthly and seasonal alkalinity, parts per million arranged by sampling stations and months*

Month	Mean monthly alkalinity at station														
	461	Little Miami	Licking	475	482	486	Great Miami	492	503	530	Kentucky	548	588	606	624
1929															
November	38	164	135	45	44	46	190	61	53	45					
December	40	175	111	47	49	47	165	47	50	38					
1930															
January	37	191	116	48	46	51	180	61							
February	44	172	90	48	51	46	213	49	61	61					
March	31	214	102	36	37	36	236	36	48	46					
April	40	201	99	26	41	30	237	40	48	49					
May	40	230	90	44		46	242	75	58	50			58	50	62
June	66	262	144	70		84	405	112	113	119			60	61	62
July	44	196	110	49		61	197	73	69	64	69	62	64	62	63
August	47	201	116	54		55	196	75	79	76	69	61	66	68	61
September	60	169	111	66		72	198	88	91	89	81	80	75	77	77
October	70	191	113	76		79	225	102	108	98	87	91	89	87	88
November	67	226	122	72		73	238	88	97	97	88	96	104	108	108
December	56	234	126	54		63	255	82	73	77	96	74	87	98	94
1931															
January													62	66	64
February													41	46	43
March													37	41	40
April													33	38	36
May													34	36	35

AVERAGES

November, 1929, to April, 1930	38	196	107	42	45	44	198	49	53	52					
May to November, 1930	58	220	116	60		68	242	87	87	86	79	78	78	75	74
November, 1930, to April, 1931													61	67	63

Alkalinities of the Little Miami, Licking, and Great Miami Rivers are in general greater than those of the main stream at their points of confluence. The average alkalinity of the Little Miami and Great Miami Rivers is approximately four times that of the Ohio River, the alkalinity of the Licking River about twice that of the main stream. From the limited data available for the Kentucky River, it would appear that the alkalinity of this tributary was approximately the same as that of the Ohio River. The excess alkalinity of the tributaries tends to increase that of the main river as it flows downstream from Cincinnati to Louisville.

Seasonal averages of alkalinity during the months of May to December, inclusive, representing months of pool stage and decreased stream flow, are decidedly higher than during the months of open channel and high stream flow, November, 1929, to March, 1930, inclusive.

In the following tabulation, Table No. 17, the concentration of alkalinity in the Ohio River at Cincinnati and Louisville, during the years 1914–1916 and 1929–30, has been compared during periods of open channel and high stream discharge and during periods of pool stage and decreased run-off.

Table No. 17.—Comparison between the concentration of alkalinity, in parts per million, in the Ohio River at Cincinnati and Louisville, in 1914–1916 and 1929–30, with varying channel conditions

Station	Year	Average for open-channel conditions	Average for pool-stage conditions	Yearly average
461	1914–1916	[illegible]	67	[illegible]
	1929–30	[illegible]	[illegible]	[illegible]
[illegible]	1914–1916	[illegible]	73	[illegible]
	1929–30	[illegible]	70	[illegible]

1914–1916.—Average January to December, 1914, inclusive. Open channel January to May, inclusive, and December. Pool stage June to November, inclusive.

1929–30.—Cincinnati: Average 14 months, November, 1929, to December, 1930, inclusive. Open channel November to April, inclusive. Pool stage May to December, inclusive.

1930–31.—Louisville: Average 13 months, May, 1930, to May, 1931, inclusive. Open channel March to May, 1931, inclusive. Pool stage May, 1930, to February, 1931, inclusive.

The data of Table No. 17 show during both investigations an increase in the concentration of alkalinity with decreased run-off in the summer and fall months. The slight differences in the alkalinity concentrations in 1914–1916 and 1929–1931 suggest that the acid iron wastes, which affect conditions in the upper river, have not increased sufficiently, during the past 15 years, to produce any material change in the alkalinity of the river between Cincinnati and Louisville.

OXYGEN RELATIONSHIPS

Changes in the sanitary condition of a stream, due to the introduction of or recovery from pollution, are indicated by variations in the dissolved oxygen and the oxygen demand. The relation between the dissolved oxygen, representing the oxygen resources of the water, and the oxygen demand, indicating its oxygen requirements, has been designated as the oxygen balance of the stream at the particular point at which these observations are available. The oxygen balance is said to be positive when the amount of dissolved oxygen exceeds the total oxygen demand; any excess of dissolved oxygen being sufficient to prevent anaerobic conditions. When the oxygen demand exceeds the dissolved oxygen, the oxygen balance is said to be negative and the deficiency in oxygen must be made up from other sources if anaerobic conditions are to be prevented below the point of observation.

Comparisons of the oxygen balance from point to point on a stream serve to show, to a certain extent, the net result of a number of separate changes which may have taken place in the dissolved oxygen and the oxygen demand between the points for which observations are available. With the information at present obtainable, it is not practicable to estimate with any degree of certainty the influence of the individual factors which affect the dissolved oxygen and oxygen demand, such as the presence of green algæ, reaeration, surface wash or ground water infiltration, sedimentation, or the flushing out of material previously deposited. The oxygen balance, therefore, serves only to indicate in a general way the trend of the several individual changes taking place between points along a watercourse due to added pollution or to natural agencies of stream purification.

In the following discussion the oxygen data have been separated to show: (*a*) Changes in the dissolved oxygen between main river sampling stations from Cincinnati to Louisville and the probable factors influencing the variations in these designated river sections, (*b*) fluctuations in the oxygen demand between the same sampling points and the factors probably influencing its change in the several river sections, and (*c*) variations in the oxygen balance through the designated sections as a result of the separate changes in dissolved oxygen and oxygen demand.

DISSOLVED OXYGEN

In Table No. 18 there are presented, in terms of concentration, monthly averages of the daily dissolved oxygen determinations during each month of observation, for all sampling stations on the main river and its tributaries. Results at the mouths of tributaries have been inserted between the main river stations designating the section of the river within which the tributary enters. For further comparison there are presented seasonal averages of dissolved oxygen during a winter and spring period, representing months of high-stream flow, open-river conditions and low-water temperatures; and, for a summer and fall period at a time of pool stage, low-stream flow and high-water temperatures.

The data of Table No. 18 indicate marked seasonal variations in the concentration of dissolved oxygen, the highest occurring in the winter and spring months of low water temperatures, the lowest in summer and fall when water temperatures are highest.

Seasonal averages at the various sampling stations during the winter period, November, 1929, to April, 1930, inclusive, representing open-river conditions, with average monthly stream flows in excess of 100,000 second-feet, show a variation in the concentration of dissolved oxygen from 11.63 parts per million, above the Little Miami River, to 9.26 parts per million in the vicinity of the Kentucky River, below which data are not available, a maximum variation of 2.37 parts per million. In the summer period of pool stage, May to November, 1930, inclusive, water entered the Cincinnati metropolitan area with an average concentration of 9.14 parts per million, lost 4.21 parts per million within the zone of pollution to station 475, and then gradually increased to over 8 parts per million in the lower section of the river. The greatest change in dissolved oxygen concentration occurred during the month of August, 1930, when the concentration changed from 8.49 parts per million, above Cincinnati, to 1.72 parts per million below the zone of pollution, a loss of 6.77 parts per million. The winter decrease in dissolved oxygen concentration of 2.37 parts per million between stations 461 and 535, which may have continued still farther downstream, took place during a period of flow of approximately 35 hours, while the summer decrease of 4.21 parts per million took place in 57 hours' flow between stations 461 and 475.

TABLE No. 18.—*Average monthly and seasonal dissolved oxygen, parts per million, arranged by sampling stations and months*

Month	Average monthly dissolved oxygen, parts per million, at station														
	461	Little Miami	Licking	475	482	486	Great Miami	492	502	535	Kentucky	540	586	605	676
1929															
November	9.70	10.94	10.20	9.27	9.40	9.78	9.30	9.06	9.47	9.08	-----	-----	-----	-----	-----
December	12.96	12.04	12.14	12.86	12.87	12.93	12.06	12.91	12.83	12.87	-----	-----	-----	-----	-----
1930															
January	12.45	12.83	12.79	12.30	12.40	12.08	12.35	12.05	-----	-----	-----	-----	-----	-----	-----
February	12.72	12.42	12.16	12.80	12.66	12.48	11.72	12.41	12.30	12.32	-----	-----	-----	-----	-----
March	11.65	11.59	11.52	11.64	11.71	11.56	11.24	11.50	11.65	11.47	-----	-----	-----	-----	-----
April	10.27	9.73	10.01	10.03	10.09	10.09	9.09	10.06	9.90	9.93	-----	-----	-----	-----	-----
May	9.11	8.30	7.70	8.40	-----	8.11	8.79	8.32	8.53	8.40	-----	-----	9.09	9.30	8.65
June	8.90	3.22	7.44	7.50	-----	7.09	9.02	7.52	8.54	8.30	8.44	8.14	8.94	9.20	8.76
July	8.16	1.07	7.09	4.06	-----	6.20	7.08	7.17	7.56	7.60	6.37	7.09	6.50	7.06	7.34
August	5.40	1.33	6.06	1.72	-----	5.30	6.72	6.41	7.20	7.10	5.93	7.30	6.06	6.78	6.97
September	8.40	2.90	5.64	2.37	-----	4.20	7.10	4.90	6.90	7.30	6.21	7.78	6.66	6.42	6.50
October	9.30	1.90	9.22	2.94	-----	4.20	8.01	5.22	7.00	8.64	7.21	8.00	7.75	7.42	7.28
November	11.20	2.00	8.45	7.59	-----	6.75	8.11	6.92	8.06	9.51	7.97	10.06	10.34	9.91	9.09
December	12.96	8.23	6.80	12.20	-----	11.19	10.47	11.08	11.96	11.67	10.06	12.21	12.40	12.11	12.04
1931															
January	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	12.19	12.47	12.30
February	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	11.08	11.30	10.88
March	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	11.27	11.04	11.17
April	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	9.19	9.47	9.14
May	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	8.61	8.14	8.61
AVERAGES															
November, 1929, to April, 1930, inclusive	11.66	11.61	11.67	11.52	11.53	11.47	11.19	11.44	9.35	9.26	-----	-----	-----	-----	-----
May to November, 1930	9.14	2.74	7.55	4.93	-----	6.09	7.92	6.64	7.80	8.34	7.01	8.22	8.09	8.02	7.81
November, 1930, to April, 1931, inclusive	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	11.08	11.29	10.77

A comparison of the dissolved oxygen concentration during the two seasonal periods shows that the average summer concentration during pool stage was 79 per cent of the winter concentration above Cincinnati, and 43 per cent just below the sewer outlets, increasing gradually to 74 per cent at the Kentucky River.

With the exception of the Little Miami River, which shows a dissolved oxygen concentration very much less than the concentration of the main stream near its point of confluence, the concentration in the remaining tributaries is not greatly different from that of the main stream at their points of entrance. The tributaries, as does the main stream, show the highest average concentration of dissolved oxygen in the winter months when the water temperature is lowest, and the lowest concentration in the summer months of high-water temperatures. In the months of July and August the concentration of dissolved oxygen in the Little Miami River decreased to about 1 part per million, due to the pollution which it received in the first few miles above its mouth.

The basic data tabulation (Table No. 9), shows that during every month of observation water entered the Cincinnati metropolitan area practically saturated with dissolved oxygen, but the actual amounts present varied from a maximum of nearly 13,000,000 pounds per day in January to a minimum of 170,000 pounds per day in October, depending upon the volume of stream flow and the water temperature. Within the zone of pollution the amount of dissolved oxygen in the stream decreased, not only because of decreased run-off but as a result of the utilization of oxygen in the oxidation of organic matter contributed by the sewage and wastes from the area. Actual amounts of dissolved oxygen just below the sewer outlets of the city varied from over 13,000,000 pounds per day in January to 36,400 pounds per day in August. At times, in the month of August, the river at station No 475, contained no dissolved oxygen, indicating its complete utilization by the sewage and wastes contributed to the stream above. Below the Cincinnati sewers the amount of dissolved oxygen in the river tends in general to increase.

TABLE No. 19.—*Average monthly changes in dissolved oxygen, between designated points on the Ohio River, expressed as the daily average, in pounds, and as the percentage change*

Month	Changes in dissolved oxygen, expressed as the daily average in pounds and as the percentage change between sampling stations									
	461 and 475		475 and 486		486 and 503		503 and 535		545 and 585	
	Pounds change	Per cent change	Pounds change	Per cent change	Pounds change	Per cent change	Pounds change	Per cent change	Pounds change	Per cent change
1929										
November	−398,730	−3.6	+308,460	+4.8	−101,880	−1.2	−384,120	−3.7	....	....
December	−68,680	−.56	+55,450	+.73	+9,724	+.10	+26,880	+.28	....	....
1930										
January	−94,130	−.66	−308,520	−2.2	....	....	....	....	....	....
February	+92,070	+.95	−231,300	−2.3	−41,980	−4.2	+96,580	+.94	....	....
March	−4,640	−.04	−58,880	−.44	+105,640	−1.4	−211,380	−1.5	....	....
April	−126,720	−2.3	+86,030	+.89	−47,720	−.34	+66,220	+.66	....	....
May	−112,330	−6.4	−68,750	−4.1	+84,190	+3.1	−9,220	−5.3	....	....
June	−170,770	−16.1	−50,820	−5.4	+143,620	+12.[illegible]	−19,380	−1.7	+122,480	+11.1
July	−180,660	−50.0	+67,120	+57.4	+19,480	+6.1	+4,880	+1.4	−31,880	−9.7
August	−130,880	−79.3	+77,240	+212.0	+29,280	+12.7	−1,730	−.96	−17,000	−8.8
September	−157,680	−73.2	+84,710	+96.5	+62,920	+28.2	+27,680	+10.2	−36,380	−13.4
October	−117,880	−68.[illegible]	+34,580	+46.0	+56,630	+32.8	+24,370	+12.9	−35,370	−12.2
November	−106,770	−31.7	−34,280	−10.6	+62,370	+21.0	+30,570	+13.4	+16,580	+4.7
December	−52,040	−3.9	−66,380	−8.0	+66,010	+7.5	−11,280	−1.3	+81,460	+2.4

In Table No. 19 there have been calculated, using the monthly estimates of stream flow and the concentration of dissolved oxygen, actual changes in the amount of dissolved oxygen, expressed as the daily average in pounds and as the percentage change from the upper to the lower sampling station, for five river sections between Cincinnati and Louisville. In the upper section of the river, stations 461 to 475, between which the Little Miami and Licking Rivers enter, the dissolved oxygen of the main stream has been corrected for tributary inflow by assuming that the difference between the amount of dissolved oxygen present at the lower station and the sum of the amounts present at the upper station and at the mouths of the two tributaries, would be indicative of the change in the main channel between the upper and lower station.

The data of Table No. 19 indicate a consistent decrease in the amount of dissolved oxygen between stations 461 and 475, the river receiving all of the sewage and industrial wastes from the Cincinnati metropolitan area between these points. The indicated decrease in dissolved oxygen in this section of the river varies from 0.04 per cent in March, to 79.3 per cent in August. In only one month, namely February, is an increase in dissolved oxygen indicated, amounting to approximately 1 per cent. Within the zone of pollution the percentage decreases in dissolved oxygen are greatest in the summer period of pool stage and high-water temperatures when stream flows approached the minimum, resulting in increased times of flow and lowest velocities through the pool. Immediately below the zone of heaviest pollution, stations 475 to 488, a decrease in dissolved oxygen is suggested in half of the months of observation and an increase during the remaining half. Percentage increases in dissolved oxygen are much greater in the summer period during pool stage and decreased stream flow than at other times. In this section of the river the increase in the amount of dissolved oxygen present varied during the months of July to October, inclusive, from 46 to 212 per cent. Below the Great Miami River, during the months of pool stage, there was a constant tendency for the dissolved oxygen to increase, while in the lower section of the stream changes were about equally divided, the magnitude becoming less as the distance from the zone of greatest pollution increased.

As estimated in the study of the precision of the oxygen determinations, changes in the amount of dissolved oxygen between successive sampling stations to be of significance, should be in excess of about ±10 per cent. Therefore, during periods when stream flows are relatively high, the indicated quantitative changes, while appearing quite substantial, are well within the probable error of the differences and therefore are of little or no significance. The significant changes in dissolved oxygen appear to be confined to the decreases which occur within the zone of heavy sewage pollution, stations 461 to 475, during the summer months of pool stage, June to November, inclusive; the substantial increases in dissolved oxygen at pool stage in the section immediately below the zone of pollution, stations 475 to 488 during July to October, inclusive, and the further and somewhat smaller increases which occur less frequently, but usually at pool stage, at points considerably removed from the sources of major pollution. In these months of significant change the data suggests rates of oxidation within the zone of pollution greater than the rates of reaeration, since there was a consistent and substantial decrease in the amount of dissolved oxygen between stations 461 and 475. Below station 475 rates of reaeration are greater than rates of oxidation as indicated by the increase in dissolved oxygen in the river.

The data of Table No. 19 further indicate that the changes in dissolved oxygen through the zone of pollution are somewhat greater during the months of highest water temperatures and tend to become less as the water temperature approaches 0° C. In general the correlation between changes in dissolved oxygen and water temperatures in this area is greater than the correlation between dissolved oxygen and times of flow past the city. These smaller decreases in dissolved oxygen in the river through Cincinnati in the months of lower water temperature suggest the operation of factors tending to build up the oxygen reserve of the stream through the zone of pollution. During the months of decreased water temperatures, biological activities are greatly retarded, requiring less dissolved oxygen in oxidation processes and at the same time the lower temperatures permit of larger amounts of oxygen being taken into solution. These phenomena should result in larger amounts of dissolved oxygen appearing in the stream below the zone of pollution, the higher residual decreasing the indicated change through the metropolitan area.

In the following tabulation (Table No. 20) changes in the amount of dissolved oxygen through the highly polluted section of the river at Cincinnati have been converted into equivalent sewered populations by assuming that the 5-day biochemical oxygen demand of combined sewage was 0.164 pound per capita per day.[14]

The data of Table No. 20 indicate that the calculated equivalent sewered populations, corresponding to the mean monthly changes in dissolved oxygen, vary from 315,000 to 1,095,000 and that the variations are similar to and are affected by the same factors that influence the changes in dissolved oxygen.

From stations 475 to 488 the indicated average gross rate of increase in dissolved oxygen, during the months of July to October, 1930, inclusive, was 0.65 pound per day per thousand square feet of water surface, varying between 0.90 pound per day in July to 0.26 pound per day per thousand square feet in October, on the assumption that the water surface area at pool stage is 94,000,000 square feet. Between stations 492 and 503, with an estimated water surface of 78,000,000 square feet, the gross rate of reaeration was 0.66 pound per per day per thousand square feet in the months of August to November, 1930, inclusive, with variations between 0.81 and 0.30 pound per day per thousand square feet.

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[14] The oxygen demand of polluted waters. E. J. Theriault, Public Health Bulletin No. 173, p. 54.

TABLE No. 20.—*Equivalent sewered populations corresponding to the mean monthly decreases in dissolved oxygen between stations 461 and 475, Table No. 19*

[Based on the assumption that the 5-day biochemical oxygen demand of combined sewage equals 0.164 pound per capita per day]

Month	Mean water temperature, ° C.	Mean time of flow, stations 461 to 475	Average monthly decrease in dissolved oxygen, pounds daily	Population equivalent to the decrease in dissolved oxygen
1930				
April	12.0	6.1	125,700	765,000
May	20.2	9.6	112,300	685,000
June	23.8	14.4	179,800	1,095,000
July	27.0	49.7	150,700	920,000
August	25.3	87.4	139,900	855,000
September	23.6	72.2	157,600	960,000
October	16.1	101.4	117,800	720,000
November	9.5	61.5	105,900	645,000
December	2.9	25.9	52,000	315,000

In the preceding discussion, only gross changes in dissolved oxygen have been considered, without correction for the changes due to oxidation processes, between the corresponding stations, as indicated by the variations in the biochemical oxygen demand. In the following section, changes in the oxygen demand are considered.

In summarizing the dissolved oxygen data, it appears that at times of open channel with stream flows past Cincinnati in excess of about 100,000 second-feet, changes in the amount of dissolved oxygen through the metropolitan area are not sufficiently great to indicate accurately the effect on the Ohio River of the sewage and other wastes from this area. When stream flows past Cincinnati decrease to 50,000 second-feet or less, giving longer periods of flow through the pool at a time when water temperatures are highest and biological activities greatest, the sewage and wastes from the metropolitan area decrease materially, and at times completely exhaust the dissolved oxygen within the zone of pollution.

OXYGEN DEMAND

In Table No. 21 the daily 5-day biochemical oxygen demand determinations at 20° C., expressed in parts per million, have been summarized as monthly averages for each month of observation at all main river and tributary sampling stations. Results at the mouths of tributaries have been inserted between the main river stations representing the section within which the tributary enters.

Table No. 21.—*Average monthly and seasonal oxygen demand, parts per million, at 20° C., arranged by sampling stations and months*

Month	Average monthly oxygen demand (5 days at 20° C.), parts per million, at stations—														
	461	Little Miami	Licking	475	482	486	Great Miami	492	502	525	Kentucky	548	595	606	624
1929															
November	2.36	2.61	3.18	2.91	3.11	2.36	4.11	2.60	2.82	2.08	-----	-----	-----	-----	-----
December	1.61	2.64	2.47	2.64	2.60	2.18	2.84	1.71	2.67	2.29	-----	-----	-----	-----	-----
1930															
January	2.08	3.01	2.38	2.30	2.35	1.96	2.59	2.69	-----	-----	-----	-----	-----	-----	-----
February	2.32	3.35	2.78	2.54	3.01	2.10	3.56	2.07	2.48	2.19	-----	-----	-----	-----	-----
March	2.11	2.79	1.98	2.23	2.26	1.77	2.74	1.90	2.44	1.71	-----	-----	-----	-----	-----
April	1.61	3.71	3.27	2.28	2.33	1.96	3.31	1.95	2.26	1.64	-----	-----	-----	-----	-----
May	1.78	4.59	3.10	2.57	-----	1.69	4.92	2.28	2.47	1.78	-----	-----	2.61	4.36	2.84
June	1.89	6.36	4.54	2.89	-----	2.08	5.06	2.86	3.28	2.06	5.29	3.97	3.19	5.19	2.60
July	1.73	8.83	5.86	3.69	-----	3.12	5.58	3.51	3.49	2.56	3.73	2.94	3.69	6.02	1.87
August	1.30	11.21	10.62	3.73	-----	3.22	4.63	3.63	3.85	2.23	2.71	2.24	2.49	3.86	2.24
September	1.64	8.76	7.71	3.54	-----	2.24	3.01	2.48	2.49	2.16	2.39	2.48	1.96	3.87	1.87
October	1.21	11.38	12.15	3.98	-----	2.34	2.40	2.21	2.66	1.88	2.27	2.10	1.47	3.01	1.74
November	1.36	13.41	12.75	5.45	-----	2.81	2.95	2.57	2.32	2.34	2.20	2.07	1.57	2.35	1.79
December	1.78	18.33	11.09	5.09	-----	4.01	4.04	3.81	4.94	2.31	2.50	2.09	1.76	2.09	2.44
1931															
January	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.29	1.80	2.02
February	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.25	1.79	1.63
March	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.36	1.87	1.25
April	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	2.15	3.05	2.81
May	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.04	2.23	1.33
AVERAGES															
November, 1929, to April, 1930, inclusive	2.04	3.18	2.66	2.50	2.61	2.05	3.20	2.15	2.12	1.64	-----	-----	-----	-----	-----
May to November, 1930, inclusive	1.56	9.21	8.10	3.69	-----	2.61	4.16	2.81	2.94	2.23	3.10	2.63	2.42	4.10	2.14
November, 1930, to April, 1931, inclusive	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.55	2.16	1.99

The concentration of oxygen demand in the tributaries (Table No. 21) is greater than that of the main river near their respective points of confluence. The highest concentration of oxygen demand occurs at the mouth of the Little Miami River, reaching a monthly average of 18.33 parts per million in December as a result of the relatively large amount of sewage entering a short distance above the mouth and the small volume of flow during the month.

At station 461, above the Cincinnati metropolitan area, located a considerable distance below the influence of upstream sources of pollution, the lowest concentration of oxygen demand occurs in the summer period when the time of flow is longest from the nearest sources of pollution, the highest concentration in winter when times of flow are less from the nearest upstream points of pollution.

Within and below the zone of pollution the highest concentration of oxygen demand without exception occurs during the summer period of pool stage at a time of low stream discharge and high-water temperature.

Yearly averages of oxygen demand concentration indicate an increase through the zone of sewage pollution, stations 461 to 475; a decrease from below the lower Cincinnati sewers to the Great Miami River; a secondary increase extending from the Great Miami River, at times as far downstream as station 503; and a decrease in the lower section of the stream between stations 503 and 598.

Seasonal averages of the oxygen demand concentration show that, in the winter period of unobstructed flow, water entered the metropolitan area with a concentration of 2.04 parts per million, which was increased 0.46 part per million to a concentration of 2.50 parts per million immediately below the zone of sewage pollution. At station 488, approximately 13 miles below the lower sewer outlets, the concentration had decreased to 2.05 parts per million, practically the same as that of the water entering the area of pollution. Immediately below the confluence of the Great Miami River the concentration of oxygen demand is somewhat higher than at the station just above but decreases to 1.64 parts per million near the mouth of the Kentucky River, representing a concentration less than that of the water entering the zone of pollution.

In the summer period of pool stage and decreased stream discharge, the concentration of 1.56 parts per million, above Cincinnati, was increased 2.13 parts per million by the sewage and wastes from the metropolitan area to a concentration of 3.69 parts per million at station 475, immediately below the sewer outlets. Below the sewers the concentration of oxygen demand fluctuates considerably in this period of pool stage, showing first a decrease to 2.61 parts per million at station 488; a slightly higher concentration, 2.81 parts per million, just below the Great Miami River, which increases to 2.94 parts per million at station 503. The concentration of 2.33 parts per million above the Kentucky River is increased to 2.63 parts per million below the confluence, followed by a decrease to 2.42 parts per million at station 598, above Louisville.

With the exception of station 461, where the average summer concentration of oxygen demand was 0.48 part per million less than the average winter concentration, the mean summer concentration at all other main river sampling stations was greater than the winter concentration, the maximum difference occurring immediately below the zone of sewage pollution where the summer concentration exceeded that of winter by 1.19 parts per million.

The actual quantity of oxygen demand present in the river at the various sampling stations, expressed as the daily average in pounds, is tabulated in the basic summaries, Table No. 9. Above the sources of pollution the monthly average amount of oxygen demand varied from 2,316,000 pounds per day in March, to 21,500 pounds per day during October, due to the variations in the volume of stream flow. Immediately below the sewers of the Cincinnati area the quantity of oxygen demand varied from 2,650,000 pounds per day in January to 72,000 pounds per day in October. Below the mouth of the Great Miami River, between stations 492 and 503, a rather consistent temporary increase in the quantity of oxygen demand carried by the river appears to take place.

The contribution of oxygen demand by the several tributaries is in general very much less than the oxygen demand present in the main stream at their points of entrance, due to their small volume of discharge. The Little Miami River, which usually has the highest concentration of oxygen demand, contributes from 1.5 to 4.5 per cent of the oxygen demand carried by the Ohio River just below its mouth at times of high stream flow, increasing to 18 per cent in the months of pool stage and decreased discharge in the main channel.

At station 598, just above Louisville, the quantity of oxygen demand is higher, during every month for which comparisons are possible, than the quantity in the water entering the Cincinnati area, in fact there is no point within the entire section of the river under observation that the quantity of oxygen demand is consistently less than the amount in the water just above Cincinnati.

In Table No. 22 the actual gross increases or decreases in the amount of 5-day oxygen demand have been assembled for each month of observation expressed in terms of the daily average, in pounds, and as the percentage change, between designated sampling stations from Cincinnati to Louisville. Corrections for the oxygen demand contributed by the Little Miami and Licking Rivers have been made for the section of the main stream into which these tributaries flow.

TABLE NO. 22.—*Average monthly changes in oxygen demand, between designated points on the Ohio River, expressed as the daily average, in pounds, and as the percentage change*

Month	Changes in oxygen demand, expressed as the daily average in pounds, and as the percentage change between sampling stations—									
	461 and 475		475 and 488		492 and 503		503 and 535		548 and 598	
	Pounds change	Per cent change	Pounds change	Per cent change	Pounds change	Per cent change	Pounds change	Per cent change	Pounds change	Per cent change
1929										
November	+431,300	+20.2	−477,650	−18.6	+221,860	+9.3	−718,400	−27.7	....	....
December	+543,370	+42.6	−332,720	−18.3	+724,510	+57.3	−275,350	−13.8	....	....
1930										
January	+334,400	+14.6	−490,890	−18.2	....	....	....	....	....	....
February	+120,290	+6.7	−324,120	−17.0	+347,960	+20.8	−228,340	−11.3	....	....
March	+155,460	+6.5	−538,670	−21.1	+659,400	+29.5	−557,210	−29.6	....	....
April	+333,460	+36.9	−158,370	−12.8	+196,940	+17.9	−369,140	−27.7	....	....
May	+142,100	+40.4	−129,710	−26.2	+22,180	+4.6	−138,550	−27.5	....	....
June	+118,340	+49.2	−24,640	−6.9	+58,890	+15.6	−78,200	−18.0	−100,120	−18.7
July	+69,770	+102.0	−21,000	−15.2	+300	+0.21	−38,320	−26.3	+34,150	+27.0
August	+46,260	+141.0	−10,630	−13.5	+6,300	+7.0	−40,430	−41.7	+7,360	+12.5
September	+43,580	+89.4	−33,600	−36.4	+960	+1.3	−10,070	−13.0	−15,780	−19.9
October	+46,330	+179.0	−29,630	−41.0	+11,260	+22.9	−17,990	−29.9	−15,210	−31.1
November	+117,260	+252.0	−79,110	−48.3	−7,850	−9.0	+1,060	+1.3	−17,060	−23.2
December	+214,010	+161.0	−72,680	−20.9	+84,440	+30.6	−190,480	−52.9	−22,870	−14.6

The data of Table No. 22 show consistent and substantial increases in oxygen demand, varying from 6.5 per cent in March to 252 per cent in November, between stations 461 and 475, located above and below, respectively, the zone of heaviest sewage pollution. The greatest percentage increases in oxygen demand occur during the summer months of pool stage. In the section between stations 475 and 488 there is a consistent tendency toward a decrease in the amount of oxygen demand, the percentage changes varying from about 7 to 48 per cent, with the greatest percentage decreases occurring in the fall and winter months when the navigation dams were raised. Below the confluence of the Great Miami River, between stations 492 and 503, the data indicate a consistent tendency toward an increase in the amount of oxygen demand present in the stream ranging from 0.21 to 57 per cent. In only one month, namely November, is a decrease in oxygen demand indicated amounting to 9.0 per cent. Below station 503 there is in general a tendency toward a decrease in oxygen demand as the lower sampling stations near Louisville are reached.

As indicated by the study of the precision of the oxygen determinations, the probable error of the monthly differences in oxygen demand between successive stations, to be of significance, should be in excess of about ± 25 per cent. In addition to the consistent tendencies shown in the variations of oxygen demand between the designated stations, the data of Table No. 22 suggest that the significant changes are limited to the increases within the zone of pollution between stations 461 and 475, during the months of pool stage, April to December 1930, inclusive, and to the decreases below the zone of pollution which occur in the months of September to November, inclusive, with similar river conditions. While the indicated consistent increases in oxygen demand, below the mouth of the Great Miami River, are in general less than the probable error of the monthly differences, they may be of significance when considered in connection with bacterial increases, described under the bacteriological findings, which appear to take place in this same section of the river.

From April to December, 1930, inclusive, the Ohio River was continuously at pool stage with but little change in gage height. Variable factors consisted of changes in water temperatures and in the rates of stream flow, the latter causing marked variations in the time and velocity of flow through the various pools. During the nine months of pool stage the estimated mean monthly times of flow through the Cincinnati district varied from 6.1 to 101.4 hours, giving average calculated velocities ranging from about 3.0 to 0.2 feet per second. For the 5-month period July to November, inclusive, the average velocity was 0.29 foot per second, sufficiently low it is believed for the settling of sewage material to have occurred in the vicinity of the various sewer outlets. In this same period of nine months, water temperatures varied from 3 to 27° C.

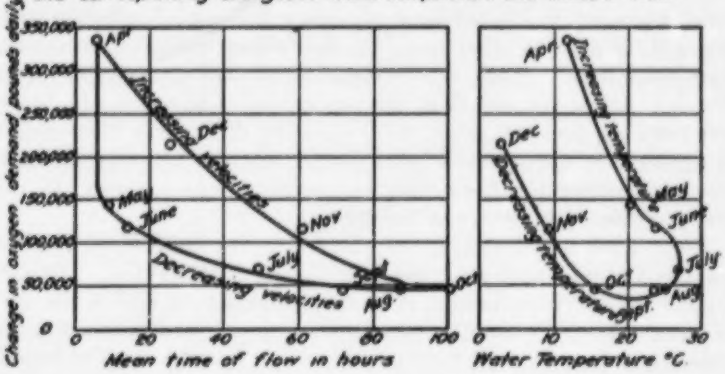
Table No. 23 summarizes the indicated monthly average increases in the amount of oxygen demand between stations 461 and 475 during the 9-month period April to December, 1930, inclusive, together with corresponding changes in the monthly mean water temperature and estimated times and velocities of flow through the Cincinnati district.

Table No. 23.—*Increases in oxygen demand between stations 461 and 475, at Cincinnati, expressed as the daily average, in pounds, for the month, and the corresponding monthly averages of water temperatures, and velocity and time of flow*

Month	Mean monthly time of flow, stations 461 to 475	Average monthly velocity of flow, stations 461 to 475	Average monthly water temperature, °C.	Average monthly increase in oxygen demand
1930				
April	6.1	5.8	12.0	333,500
May	9.6	2.1	20.2	142,100
June	14.4	1.3	23.5	118,300
July	49.7	.41	27.0	69,900
August	87.4	.22	26.3	46,300
September	72.3	.28	23.6	43,600
October	101.4	.20	16.1	46,300
November	61.5	.33	9.5	117,300
December	26.9	.74	2.9	214,000

During the period of continuous pool stage the indicated gross increase in oxygen demand varied from a daily average of 333,500 pounds in April to 43,600 pounds in September, a maximum variation of nearly 290,000 pounds per day.

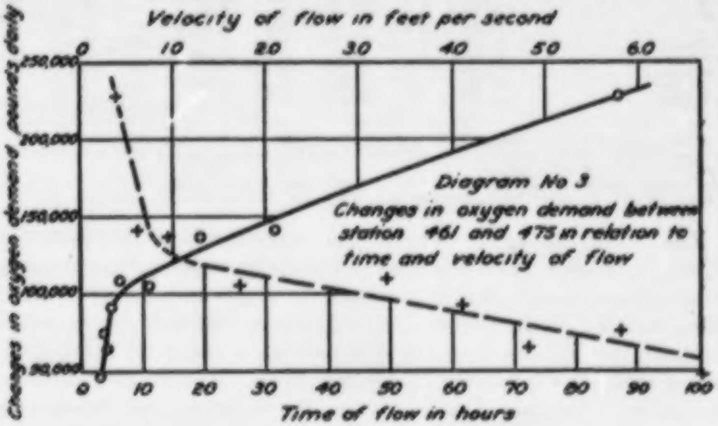
Diagram No 2 - Changes in oxygen demand, Station 461 to 475 and corresponding changes in water temperature and times of flow



The data of Table No. 23 are shown graphically in Diagram No. 2 and indicate variations in the increase in oxygen demand past Cincinnati compared with changes in times of flow and water temperatures.

Diagram No. 2 indicates rather regular fluctuations in the gross change in oxygen demand past Cincinnati from month to month with variations in water temperature and times and velocity of flow through the pool. Decreasing velocities and increasing water temperatures, in the period April to July, combined to give smaller indicated increases through the area while increasing velocities and decreasing water temperatures, in the months of October, November, and December, produced a larger indicated increase in oxygen demand through the area.

The indicated gross changes in the amount of oxygen demand within the zone of pollution (Table No. 23) have been calculated on the basis of a 5-day biochemical oxygen demand at 20° C. at stations 461 and 475. The results at station 475 indicate the change due to the effects of varying river temperatures, different times of flow from the various sources of pollution to station 475, and to the effect of sedimentation in the months of greatly decreased river velocities.



In Table No. 24 an attempt has been made to correct the gross changes in the amount of oxygen demand increase through Cincinnati for these several factors influencing the changes. The data of Table No. 24 have been shown graphically in Diagram No. 3.

Corrections for the time of flow between the points of pollution and station 475 (Table No. 24) reduce in every instance the increase in oxygen demand through the Cincinnati area, while temperature corrections decrease the changes in the months when water temperatures were below 20° C. and increase them when water temperatures were above 20° C. .Corrections for the removal of oxygen demand by sedimentation tend of course to give a larger increase through the section.

TABLE No. 24.—*Increases in oxygen demand between stations 461 and 475, expressed as the daily average in pounds, corrected for river temperature, time of flow below sources of pollution and sedimentation*

Month	Gross increase in oxygen demand, pounds per day	Oxygen demand after correction for—						Population equivalent of the corrected change in oxygen demand
		Temperature		Time of flow		Sedimentation		
		Mean river temperature	Oxygen demand corrected for temperature, pounds daily [1]	Mean time of flow, hours	Oxygen demand corrected for time of flow, pounds daily [2]	Mean velocity of flow	Oxygen demand corrected for sedimentation, pounds daily [3]	
1930		° *C.*				*Sec.-ft.*		
April	333,500	12.0	232,000	6.1	228,000	5.5	228,000	1,390,000
May	142,100	20.2	143,000	9.6	140,000	2.1	140,000	855,000
June	118,300	23.8	141,000	14.4	137,000	1.3	137,000	835,000
July	69,800	27.0	96,000	49.7	87,300	.41	109,000	665,000
August	46,300	25.3	59,000	87.4	51,000	.22	73,000	445,000
September	43,600	22.6	51,000	72.2	45,000	.26	64,000	390,000
October	46,200	16.1	38,000	101.4	33,000	.20	47,000	290,000
November	117,300	9.5	72,000	61.5	64,000	.33	91,000	555,000
December	214,000	2.9	98,000	25.9	93,000	.74	103,000	630,000

[1] Using values of *K* at different temperatures. Public Health Bulletin 173, p. 141.

[2] Assuming all pollution entering river at midpoint of section and time of flow to station 475 as half the time of flow through whole section.

[3] Assuming the removal of oxygen demand by sedimentation as follows: April to June, inclusive, none; July, 20 per cent; August to November, inclusive, 30 per cent; December, 10 per cent.

The relatively large temperature corrections in the months of April, November, and December so reduce the gross indicated changes in oxygen demand that in relation to time and velocity of flow (Diagram No. 3) they become entirely consistent and show a decided tendency for the increases in demand, as a result of the pollution added through Cincinnati, to become less with increasing times and decreasing velocities of flow. When the velocities fall below 1 foot per second, increases in the oxygen demand fall off quite rapidly. In comparison with the temperature correction, those for the effect of sedimentation and time of flow between sources of pollution and station 475, have comparatively little effect on the change in oxygen demand through the polluted section.

If it is assumed that the 5-day biochemical oxygen demand of combined sewage is 0.164 pound per capita per day, the equivalent sewered population represented by the changes in oxygen demand, during the months of significant increase through the metropolitan area, fluctuates between 1,390,000 in April, the month of greatest stream flow and highest velocity, and 290,000 in October, the month of lowest stream discharge and least velocity. Since the equivalent sewered populations are derived by the use of a constant factor from the changes in oxygen demand, they have the same tendency to become less as the times of flow through the section increase and river velocities decrease. If the month of April, with a relatively short period of flow through the metropolitan area (6.1 hours) and high velocity (5.8 feet per second), is taken to be indicative of the normal variations in oxygen demand through the Cincinnati area, then that which might be termed the "unaccounted for" demand during the remaining 8 months (change during April less changes in the succeeding months) varies between 88,000 and 181,000 pounds per day, equal to equivalent sewered populations of 535,000 in May and 1,100,000 in October, respectively. (Table No. 24.)

A portion at least of the decrease in dissolved oxygen through the same river section was utilized in satisfying the oxygen demand of the organic matter added by the sewage. Although the increase in oxygen demand through the polluted section becomes less in the summer period of lowest velocities, the increase is in excess of the decrease in dissolved oxygen, so that the data suggest either errors in the assumptions for the correction of the effect of temperature, time of flow, and sedimentation or the oxidation of organic material of the wastes by oxygen supplied as a result of reaeration in the long time of flow not indicated in the dissolved oxygen determination. In the latter case the so-called unaccounted for change in oxygen demand through the polluted zone should be an index of the reaeration taking place in this section of the river and is further discussed in the oxygen balance section.

Immediately below the zone of pollution a decrease in oxygen demand is consistently indicated and of such magnitude, in at least three months, to be of possible significance. Between stations 475 and 488 very little additional sewage pollution reaches the river and normal oxidation processes reduce the amount of oxidizable material remaining in the sewage. The limited data available seem to indicate that with increasing velocities in November and December, possibly disturbing sludge deposits, larger amounts of oxidizable material reached this section of the river to be oxidized by natural processes of stream purification.

The available and significant oxygen demand results indicate that at times of open river with stream flows greater than about 100,000 second-feet, the effect of sewage, industrial wastes, and other pollution from the Cincinnati metropolitan area is not sufficient to produce measurable changes, as indicated by the oxygen demand determination, in the stream below the sources of pollution. At times of decreased run-off when stream flows reach about 50,000 second-feet or less, the effect of sewage and wastes is probably great enough to produce measurable changes by the oxygen demand determination provided unobstructed flow prevails in the river. If, as in the present instance at Cincinnati, the sewage and wastes are discharged into a stream in which the velocities of flow are greatly reduced, the effect of pollution may be greatly underestimated, due to the operation of factors tending to reduce materially the effect of the pollution in the watercourse. On the other hand, at times of increasing velocities, the stirring up of previously deposited material may have a tendency to produce conditions from which the effect of pollution may be overestimated.

OXYGEN BALANCE

In Table No. 25 the observed gross quantitative changes in dissolved oxygen and oxygen demand of Tables Nos. 19 and 22, expressed as the daily average in pounds, have been combined to show the average monthly variations in oxygen balance [19] within the several sections of the Ohio River under observation and as the percentage increase or decrease between the upper and lower station of the river sections.

TABLE No. 25.—*Average monthly changes in oxygen balance, between designated points on the Ohio River, expressed as the daily average, in pounds, and as the percentage change*

Month	Changes in oxygen balance, expressed as the daily average, in pounds, and as the percentage change between sampling stations									
	461 and 475		475 and 492		492 and 503		503 and 536		548 and 566	
	Pounds change	Per cent change	Pounds change	Per cent change	Pounds change	Per cent change	Pounds change	Per cent change	Pounds change	Per cent change
1929										
November	−770,080	−11.9	+871,110	+15.3	−377,450	−5.0	+394,280	+6.6	....	....
December	−896,050	−7.8	+389,170	+5.5	−714,780	−8.6	+301,940	+4.0	....	....
1930										
January	−428,530	−3.7	+171,370	+1.5	....	....	....	....	....	....
February	−28,230	−.37	+102,930	+1.3	−309,980	−4.7	+823,870	+4.1	....	....
March	−160,160	−1.5	+490,080	+4.5	−452,780	−4.1	+845,880	+5.9	....	....
April	−450,180	−9.8	+198,370	+4.7	−244,670	−5.4	+414,390	+9.6	....	....
May	−254,420	−18.3	+62,980	+5.5	+32,910	+2.7	+129,330	+10.8	....	....
June	−298,110	−34.2	−28,180	−4.5	+64,720	+13.8	+38,870	+8.4	+232,610	+89.5
July	−230,420	−94.3	+108,130	+894.0	+19,160	+12.6	+42,900	+26.1	−88,040	−22.4
August	−186,180	−129.0	+87,970	+295.0	+16,930	+24.5	+88,700	+45.6	−24,380	−18.0
September	−201,200	−121.0	+88,370	+253.0	+61,940	+81.6	+32,120	+28.3	−17,470	−10.3
October	−164,160	−113.0	+54,180	+287.0	+45,350	+67.7	+60,280	+35.8	−10,160	−6.4
November	−223,080	−77.7	+54,860	+85.9	+70,220	+47.4	+28,810	+17.8	+22,590	+11.9
December	−266,050	−35.4	+6,230	+1.3	−19,430	−3.7	+179,280	+35.8	+54,330	+7.2

The changes in oxygen balance (Table No. 25) indicate consistent decreases between stations 461 and 475, due, as already determined, to the decreases in dissolved oxygen and increases in oxygen demand as a result of sewage pollution within this section of the river. The greatest percentage reductions occur in the summer and fall months of pool stage, June to December, 1930, inclusive, varying from 34 to 129 per cent, with changes greater than 100 per cent occurring in the months of August, September, and October at a time when stream flows were the lowest. In the section of the river between stations

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[19] An increase in dissolved oxygen and a decrease in oxygen demand increases the oxygen balance by an amount equal to the separate changes; a decrease in dissolved oxygen and an increase in oxygen demand decreases the oxygen balance by an amount equal to the sum of the separate changes. Increases in both dissolved oxygen and oxygen demand increase the oxygen balance if the increase in dissolved oxygen exceeds that of the oxygen demand, the increase being equal to the amount of dissolved oxygen less the oxygen demand; but if the increase in oxygen demand exceeds that of the dissolved oxygen, then the oxygen balance decreases by an amount equal to the oxygen demand minus the dissolved oxygen. In a similar manner, decreases in both constituents result in a decrease in oxygen balance if the decrease in dissolved oxygen is greater than the decrease in oxygen demand, or an increase in oxygen balance if the decrease in oxygen demand exceeds the decrease in dissolved oxygen.

475 and 488, with the exception of May, when a decrease in oxygen balance amounting to 4.5 per cent is indicated, there was a constant tendency toward a substantial increase in oxygen balance varying from 1 per cent to over 800 per cent with the largest consecutive increases taking place in the months of pool stage, July to November, inclusive. Below station 488, there is a tendency for the oxygen balance to improve as far downstream as station 535, especially in the summer period of pool conditions. In the lower sections of the river the percentage changes are comparatively small, but show a tendency toward a decrease in oxygen balance just above Louisville. In a total of 33 monthly observations below station 488, increases in oxygen balance are indicated in 23 months (70 per cent) and decreases in 10 months (30 per cent) of observation.

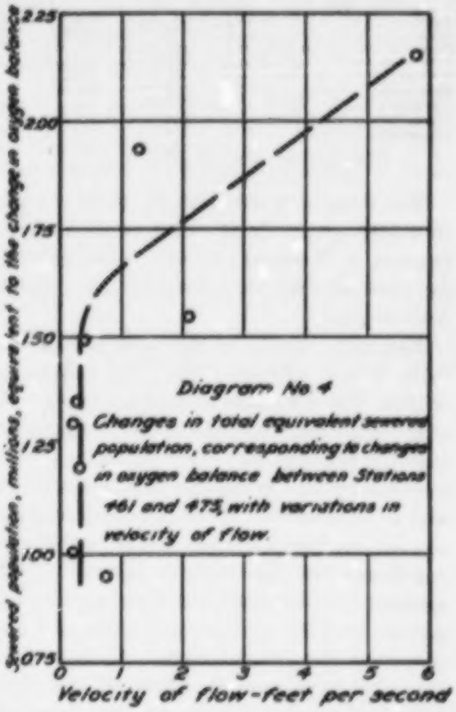

Diagram No 4

Changes in total equivalent sewered population, corresponding to changes in oxygen balance between Stations 461 and 475, with variations in velocity of flow

At the mouth of the Great Miami and Kentucky Rivers the dissolved oxygen always exceeds the total oxygen requirements of these streams, and their inflow tends to improve the oxygen balance of the main channel. In the months of May to December, inclusive, at the mouth of the Little Miami River, and during July to December, inclusive, at the mouth of the Licking River, the total oxygen requirements of the water exceeded the amount of dissolved oxygen present and the effect of these tributaries, especially the Little Miami River, was to decrease the oxygen balance of the main river below their points of confluence within the polluted section.

The average monthly decreases in dissolved oxygen (Table No. 19), and the increases in oxygen demand (Table No. 22), between stations 461 and 475, with corrections for river temperature, time of flow from the sources of pollution and sedimentation, are assembled in Table No. 26. The changes in dissolved oxygen and oxygen demand have been expressed in terms of equivalent sewered population and as the total equivalent sewered population corresponding to the change in oxygen balance.

TABLE No. 26.—*Changes in dissolved oxygen, oxygen demand, and oxygen balances between stations 461 and 47[illegible], at Cincinnati, during the period of pool stage April to December, 1930, inclusive, expressed as the daily average in pounds and as the equivalent sewered population*

Month	Dissolved oxygen		Oxygen demand		Oxygen balance	
	Decrease in thousands of pounds	Population equivalent, thousands	Increase in thousands of pounds	Population equivalent, thousands	Decrease in thousands of pounds	Population equivalent, thousands
1930						
April	128.7	785.0	225.0	1,370.0	353.7	2,155.0
May	112.3	685.0	140.0	855.0	252.3	1,540.0
June	179.8	1,095.0	137.0	835.0	316.8	1,930.0
July	150.7	920.0	109.0	665.0	259.7	1,485.0
August	139.9	855.0	73.0	445.0	212.9	1,300.0
September	157.6	960.0	64.0	390.0	221.6	1,350.0
October	117.8	720.0	47.0	290.0	164.8	1,010.0
November	105.8	645.0	91.0	555.0	196.8	1,200.0
December	52.0	315.0	103.0	630.0	155.0	945.0
Average	126.8	773.3	110.2	661.7	237.0	1,435.0

The data of Table No. 26, total population equivalents, are shown in relation to velocity of flow in Diagram No. 4, which indicates in general a decrease in the corresponding total equivalent sewered population with decreases in the velocity of flow through the Cincinnati pool.

Estimates made at the time of the 1914–1916 investigation of the Ohio River indicated that the industrial wastes reaching the river within the Cincinnati metropolitan area were equal, in terms of equivalent sewered population, to approximately 2.6 times the actual sewered population. On this same basis the total equivalent sewered population at Cincinnati and vicinity at the present time would be about 2,160,000. The ratio of industrial-waste pollution to the sewage pollution would seem to be somewhat high under existing conditions in the stream because of the elimination of the large amounts of brewery and distillery wastes since the previous investigation, and the reduced activities of many of the remaining industrial plants at the present time. If, however, April with its short time of flow and high velocity through the section, is assumed as representative of normal conditions, the calculated total sewered population equivalent to the combined changes in dissolved oxygen and oxygen demand of 2,155,000 (Table No. 26), agrees closely with the estimated total equivalent population.

Assuming that the month of April is representative of normal river conditions, the remaining eight months show calculated equivalent sewered populations less than that of April, varying from 225,000 in June to 1,210,000 in December, with corresponding oxygen balances below that of April, varying between 36,900 pounds per day in June to 198,700 pounds per day in December. If it is further assumed that the difference in oxygen balance between that of April and the remaining months is representative of the reaeration taking place between stations 461 and 475, then the amount of reaeration expressed in pounds per day per thousand square feet of water surface, on the basis of 94,600,000 square feet of total water surface, would be as indicated in Table No. 27.

TABLE No. 27.—*Estimated rates of reaeration between stations 461 and 475, expressed in terms of pounds per day per thousand square feet of water surface, calculated from the amount by which the oxygen balance during May to December, 1930, inclusive, varied from that of April, 1930*

Month	Total reaeration, pounds per day	Reaeration in pounds per day per thousand square feet of water surface	Month	Total reaeration, pounds per day	Reaeration in pounds per day per thousand square feet of water surface
1930			October	188,900	2.00
May	101,400	1.07	November	156,900	1.66
June	36,900	.39	December	198,700	2.10
July	94,000	.99	Average	131,200	1.39
August	140,800	1.49			
September	132,100	1.40			

With the exception of the month of June, which for some reason is considerably below the remaining months, the indicated rates of reaeration are fairly constant, varying between 0.99 and 2.10 pounds per day per thousand square feet of water surface and averaging 1.39 pounds per day per thousand square feet, with a tendency to increase as the velocity of flow increases.

During the month of April, with its relatively short time of flow through the section under observation, some reaeration undoubtedly took place tending toward a reduction in oxygen demand and a reduced oxygen balance. The actual rates of reaeration in the months of May to December are, therefore, probably higher than the calculated rates of Table No. 27.

TABLE No. 28.—*Calculated rates of reaeration, pounds per day per thousand square feet of water surface, between designated points on the Ohio River below Cincinnati.*

Month	Calculated rates of reaeration (pounds per day per thousand square feet)		
	Station 475 to 488 [1]	Station 492 to 503 [2]	Station 503 to 535 [3]
April	2.09	Negative.	1.73
May	.67	0.41	.54
June	Negative.	1.09	.25
July	1.15	.25	.18
August	.94	.22	.16
September	.94	.79	.13
October	.57	.86	.17
November	.58	.90	.16
December	.07	Negative.	.78
Average	.88	.61	.46

[1] Water surface area 94,000,000 square feet.
[2] Water surface area 75,000,000 square feet.
[3] Water surface area 239,000,000 square feet.

Below the zone of pollution, during the months of pool conditions, there is a marked tendency for the oxygen balance to improve, the oxygen demand decreasing and the supply of available dissolved oxygen increasing. In Table No. 28 the changes in oxygen balance, in the three river sections below the Cincinnati sewers, have been converted into rates of reaeration in pounds per day per thousand square feet of water surface.

Within each river section the rates vary to a considerable extent but the general average indicates a decrease in the rate of reaeration as the distance below the points of major pollution increases. Rates of reaeration within the zone of greatest pollution also appear to be higher than the rates in the sections below which the additional pollution reaching the stream is negligible.

SUMMARY OF THE OXYGEN RELATIONSHIPS

A study of the precision of the oxygen determinations indicates that, to be of significance, changes in dissolved oxygen and oxygen demand, between successive sampling stations, should be in excess of about ± 10 per cent and ± 25 per cent, respectively.

Changes in the dissolved oxygen and oxygen demand are usually less than the probable error of the differences in monthly means when the flow of the Ohio River past Cincinnati is about 100,000 second-feet or greater and therefore are of little significance in determining quantitatively the effect of sewage from the metropolitan area. When the flow in the river decreases to about 50,000 second-feet or less, pollution from this area has a marked effect on the river at Cincinnati, reducing, and at times completely exhausting, the dissolved oxygen in the water and increasing the oxygen demand in significant amounts.

The observed changes in the oxygen balance past Cincinnati, in a period of normal river velocities and times of flow, suggest a total equivalent sewered population of about 2,155,000 within the metropolitan district, of which about 601,000, or 28 per cent, is actual sewered population. Such an equivalent sewered population should contribute to the river oxidizable material having an oxygen demand value of approximately 353,000 pounds per day.

During the summer and fall period, April to December, 1930, the average amounts of dissolved oxygen and oxygen demand above Cincinnati were 9.70 and 1.60 parts per million, respectively. For the contribution of 353,000 pounds of oxidizable material to produce an increase in oxygen balance greater than 10 per cent, the flow past Cincinnati should be 80,000 second-feet or less, which is in close agreement with the actual observed flows in the river that do produce significant changes in the differences in monthly averages between sampling stations above and below the city.

The oxygen relationships suggest rates of reaeration above Cincinnati at least equal to those of oxidation, since the water which enters the metropolitan area has a substantial oxygen demand but is nearly saturated with dissolved oxygen. Within the zone of heavy sewage pollution, rates of oxidation exceed those of reaeration since there is a constant tendency for the dissolved oxygen to decrease in this section of the stream. Below the zone of pollution, rates of reaeration are greater than those of oxidation, since the dissolved oxygen tends to increase while at the same time the oxygen demand decreases.

In periods of pool stage the decrease in dissolved oxygen within the zone of pollution is fairly constant with changes in time and velocity of flow, but the change in oxygen demand has a marked tendency to become less as the velocities within the pool decrease. Smaller decreases in oxygen demand influence changes in the oxygen balance and at such times the effects of pollution on the river may be considerably underestimated. As the river velocities increase, with the possibility of disturbing sludge deposits, the effects of added pollution may be considerably overestimated at times of scour.

The satisfaction of oxygen demand, within the polluted zone, in excess of the decrease in oxygen demand, suggests an average seasonal rate of reaeration, in the months of April to December, inclusive, of about 1.40 pounds per day per thousand square feet of water surface, but ~~varying considerably from month to~~ month. Consistent increases in dissolved oxygen and decreases in oxygen demand below the zone of highest pollution, in the months of April to December, inclusive, suggest average rates of reaeration in the lower section of the river varying from 0.88 to 0.45 pound per day per thousand square feet of water surface, with a tendency for the rates to decrease as the distance from the zone of pollution increases and the normal oxygen relationships in the stream are again restored.

COMPARISON BETWEEN THE 1914–1916 AND 1929–1931 OXYGEN RELATIONSHIPS BELOW CINCINNATI AND LOUISVILLE

Determinations of the initial dissolved oxygen and of the biochemical oxygen demand, after 24 hours' incubation at 20° C., were made during the 1914–1916 survey on samples collected from the Ohio River at a number of stations between Cincinnati and Louisville, during the 12-month period May, 1914, to April, 1915, inclusive. Of this period, June to November, 1914, inclusive, is representative of summer conditions with Dam No. 37 in operation, forming a pool through the Cincinnati metropolitan area, and the months of December, 1914, to March, 1915, inclusive, of winter conditions with the flow in the river unobstructed by the navigation dam below the city. Such a division of the data permits comparisons between similar channel conditions below Cincinnati in 1929–30, in which the months of November, 1929, to April, 1930, inclusive, have been taken as representative of present winter conditions with unobstructed flow in the river, and the months of May to November, 1930, inclusive, of present summer pool conditions and minimum stream flow.

In Table No. 29–A, the 1914–15 oxygen results have been summarized to show for sampling stations below Cincinnati at which data are available, seasonal averages of initial dissolved oxygen and biochemical oxygen demand, after five days' incubation at 20° C., calculated from the 24-hour demands, both expressed as the daily average in pounds.

In Table No. 29–B, similar calculations of seasonal averages have been made for 1929–30, using, where possible, data collected at the same sampling stations that were used during the 1914–1916 survey. Seasonal averages show winter conditions of unobstructed flow and summer pool conditions. Comparisons between the results of the past and present survey are possible only as far downstream as the Great Miami River, since oxygen determinations are not available in 1914–15 at stations between the Great Miami and Louisville.

The ratio of dissolved oxygen to the oxygen demand is indicative of the amount of available oxygen in excess of the oxygen requirements at the several sampling points, and the changes in ratio indicate whether or not oxygen replenishment is proceeding at rates faster than the rates of oxygen withdrawal for use in oxidation processes. Ratios of dissolved oxygen to oxygen demand, based on the average seasonal amounts, have been included in Table No. 29.

TABLE No. 29.—*Comparison between the seasonal averages of dissolved oxygen and oxygen demand, expressed as the daily average, in pounds, at sampling stations in the vicinity of Cincinnati during 1914–1916 and 1929–30*

A (1914–1916) RESULTS

Station	Mean discharge, sec.-ft.	Dissolved oxygen	5-day oxygen demand, 20° C.	Ratio dissolved oxygen to oxygen demand	Mean discharge, sec.-ft.	Dissolved oxygen	5-day oxygen demand, 20° C.	Ratio dissolved oxygen to oxygen demand
	December, 1914, to March, 1915, inclusive. Winter open channel				June to November, 1914, inclusive. Summer pool stage			
461	158,800	9,183,970	3,186,310	2.9	16,600	703,920	185,100	3.8
475	150,800	10,285,400	5,067,680	2.0	16,900	598,040	351,360	1.7
482	150,300	10,294,370	4,734,970	2.2	16,900	670,560	299,720	2.2
486	150,300	10,235,730	4,497,920	2.3	16,900	692,560	309,750	2.5
492	157,100	10,646,930	5,096,080	2.1	17,980	735,310	312,210	2.3

B (1929–1930) RESULTS

Station	Mean discharge, sec.-ft.	Dissolved oxygen	5-day oxygen demand, 20° C.	Ratio dissolved oxygen to oxygen demand	Mean discharge, sec.-ft.	Dissolved oxygen	5-day oxygen demand, 20° C.	Ratio dissolved oxygen to oxygen demand
	November, 1929, to April, 1930, inclusive. Winter open channel				May to November, 1930, inclusive. Summer pool stage			
461	146,700	9,366,560	1,666,830	5.6	11,600	871,410	166,440	5.2
475	157,700	9,865,050	2,122,290	4.6	11,900	441,550	199,790	2.2
483	156,000	9,899,000	2,209,040	4.5				
486	156,200	9,837,980	1,726,900	5.7	11,900	466,110	152,880	3.0
492	166,500	10,472,370	2,004,560	5.2	12,900	516,770	186,640	2.8

In both winter periods of open channel, with stream flows in excess of 150,000 second-feet, there was a tendency for the dissolved oxygen to increase through and below the Cincinnati metropolitan area as far downstream as the Great Miami River. In these same winter periods, the oxygen demand increased through the zone of pollution and then, sometimes with fluctuations, gradually decreased below the sources of pollution. During the winter of 1929–30, the dissolved oxygen in the river at Cincinnati was slightly less than the amount present in the winter of 1914–15, but the oxygen demand in 1929–30 varied at the different stations from 39 to 53 per cent of that present in the winter of 1914–15, conditions which gave approximately twice the ratio of dissolved oxygen to oxygen demand at the various points below Cincinnati during the winter of 1929–30.

During the summer of 1930, average stream flows were approximately 75 per cent of those during 1914. The amount of dissolved oxygen and oxygen demand present in the water below Cincinnati in the summer of 1930 was consistently lower than in the summer of 1914, the dissolved oxygen varying from about 70 to 80 per cent, and the oxygen demand from 60 to 70 per cent of that present during the former survey. The almost similar reductions in the amounts of available and required oxygen resulted in but little differences in the ratios of dissolved oxygen to oxygen demand during the two summer periods of observation, those of the summer of 1930, at each station, being somewhat higher than those of the summer of 1914.

Of the seasonal changes between 1914–1916 and 1929–30, that of the greatest significance appears to be the very great reduction in the amount of oxygen demand in the river at practically all times both above and below the zone of pollution at Cincinnati since 1914–1916. Influencing this change is possibly the removal of considerable amounts of brewing and distilling wastes and the general curtailment of activities in the remaining industrial establishments at the present time.

On the basis of seasonal averages the oxygen relationships indicate but little change in the sanitary condition of the Ohio River below Cincinnati during the 15 years since the previous survey. During the present investigation, however, there were several days in the month of August, 1930, when the average monthly discharge at Cincinnati was about 4,000 second-feet, that the dissolved oxygen immediately below the city was completely exhausted. It seems reasonable to assume that, in a considerable section of the stream in the vicinity of the sewer outlets, similar critical oxygen conditions may have prevailed at times, due to accumulations of sludge which may have collected during the long period of pool stage. The effect of canalization at Cincinnati appears to have promoted sedimentation to form sludge deposits in the backwater behind the dam, which in turn exert their influence on the dissolved oxygen of the water, producing critical oxygen conditions in the vicinity of the sewer outlets rather than at points farther downstream as is usually the case in streams having unobstructed flow.

Critical oxygen conditions will occur more frequently in the future at Cincinnati, at times of decreased run-off, as the sewage and industrial waste pollution from the district increases. Any conditions favorable to sedimentation and the formation of sludge deposits in the pool, such as extended periods of pool stage or the construction of permanent dams below the city, preventing natural scour in the channel through the metropolitan area, will materially increase the frequency and duration of critical oxygen conditions at Cincinnati.

In the section of the river through Louisville, data relative to the oxygen relationships in the stream are available during the 1914–1916 investigation at sampling stations located at Mile 598, 611, and 619, for an 11-month period June, 1914, to April, 1915, inclusive. The months of June to November, 1914, are representative of summer, the months of December, 1914, to March, 1915, inclusive, of winter conditions. In both seasonal periods of 1914–15 the flow in the river was through the pool above Dam No. 41, then in open channel below the dam. In the previous survey, sampling stations 593 and 611 were located above and below, respectively, the sources of pollution from the Louisville metropolitan area.

Table No. 30–A is a summary of seasonal averages of dissolved oxygen and oxygen demand, expressed as daily averages in pounds, representing open river and pool conditions at Louisville in 1914–15. Ratios of the available to the required oxygen at the several sampling stations are also included.

The data of the present survey cover the 13 months' period May, 1930, to May, 1931, inclusive, at sampling stations located at Mile 598, 605, and 624, and may be divided into periods representative of summer pool conditions throughout the section of the river under observation by grouping the months of May to November, 1930, inclusive; a winter period, also representative of pool conditions, using the months of December, 1930, to February, 1931, inclusive; and a spring period of relatively high discharge with pool conditions above Dam No. 41 and unobstructed flow below, represented by the months of March to May, 1931, inclusive. A portion of the sewage from the Louisville area enters the Ohio River between stations 598 and 605, the remainder between station 605 and Mile 611. Seasonal averages of the quantity of dissolved oxygen and oxygen demand, also the ratios of dissolved oxygen to oxygen demand, for open river and pool conditions in 1930–31 are summarized in Table No. 30–B.

Comparing first the oxygen relationships in the various seasonal periods of 1930–31 (Table No. 30–B) the dissolved oxygen is lowest during the summer period of pool stage, while in the winter period of pool stage and spring season of unobstructed flow the amount of dissolved oxygen present in the river was three and eleven times, respectively, that of the summer period.

The amount of oxygen demand in the river was not essentially different in the summer and winter periods of pool stage but the spring demand during unobstructed flow was over five times the demand at pool stage.

TABLE No. 30.—*Comparison between the seasonal averages of dissolved oxygen and oxygen demand, expressed as the daily average in pounds, at sampling stations in the vicinity of Louisville, Ky., during 1914–16 and 1930–1931*

A (1914-1916 RESULTS)

Station	June to November, 1914, inclusive. Summer period			December, 1914, to March, 1915, inclusive. Winter period		
	Dissolved oxygen	5-day oxygen demand 20° C.	Ratio dissolved oxygen to oxygen demand	Dissolved oxygen	5-day oxygen demand, 20° C.	Ratio dissolved oxygen to oxygen demand
598	945,610	286,300	3.3	12,170,960	5,462,610	2.2
611	942,760	297,950	3.2	12,209,230	5,498,530	2.2
619	953,600	288,300	3.3	12,208,990	5,459,930	2.2

Mean discharge, June to November, 1914, 21,000 second-feet. December, 1914 to March, 1915, 151,600 second-feet.

B (1930-31 RESULTS)

Station	May to November, 1930, inclusive. Summer pool			December, 1930, to February, 1931, inclusive. Winter pool			March to May, 1931, inclusive. Spring open channel		
	Dissolved oxygen	5-day oxygen demand, 20° C.	Ratio dissolved oxygen to oxygen demand	Dissolved oxygen	5-day oxygen demand, 20° C.	Ratio dissolved oxygen to oxygen demand	Dissolved oxygen	5-day oxygen demand, 20° C.	Ratio dissolved oxygen to oxygen demand
598	641,720	200,490	3.2	1,957,700	225,450	8.7	7,299,900	1,290,930	5.6
605	684,930	334,270	2.0	1,995,570	311,510	6.4	7,364,900	2,012,650	3.7
624	625,560	185,890	3.4	1,929,460	312,100	6.2	7,269,260	1,622,610	4.5

Mean discharge, May to November, 1930, 13,900 second-feet. December, 1930, to February, 1931, 31,400 second-feet. March to May, 1931, 143,800 second-feet.

Each of the 1930–31 seasonal averages shows an increase in dissolved oxygen between stations 598 and 605, followed by a decrease between stations 605 and 624. Increases in the amount of dissolved oxygen between the upper stations and decreases between the lower stations are progressively greater in the following order of river conditions: Summer pool stage, winter pool stage, and spring open channel.

In general, increases in oxygen demand occur between stations 598 and 605, followed by decreases between stations 605 and 624. The increase in oxygen demand in the upper section of the river and the decrease in the lower is smallest at times of pool stage and greatest in the spring period of open channel.

The lowest ratio of dissolved oxygen to oxygen demand occurs during pool conditions at station 605 when there was twice as much dissolved oxygen as oxygen demand, and the highest ratio occurred in winter at station 598 when the dissolved oxygen was nearly nine times the oxygen demand.

The minimum daily concentration of dissolved oxygen within the Louisville area was recorded at station 624 during September as 4.89 parts per million, equivalent, at the river temperature on that day, to a saturation value of about 58 per cent. Since this point was approximately 15 miles below the zone of pollution, lower dissolved oxygen concentrations probably occurred within the zone of sewage pollution in the vicinity of some of the sewer outlets due to sludge deposits. While critical oxygen relationships may have been approached at times in the summer of 1930, due to the extremely low water conditions and the long period of pool stage, it seems reasonable to assume that at times of normal stream flow and channel conditions the pollution from the Louisville area should not produce objectionable conditions either within or below the zone of sewage pollution.

As in the section of the river at Cincinnati, any change in channel conditions tending to increase the length of pool stage periods or preventing natural scour in the river through the zone of pollution will permit the accumulation of sludge deposits, which at times of higher water temperatures will materially increase the effect of sewage pollution resulting in critical oxygen conditions within the zone of pollution near the larger sewer outlets.

Comparing next the oxygen relationships at Louisville in the summer and winter periods of 1914–15 (Table 30–A) the data indicate that in winter the amount of dissolved oxygen present was approximately 13 times the amount present in summer, and the winter oxygen demand about 19 times that of summer. In the summer period the amount of dissolved oxygen was approximately three times the oxygen demand, while in the winter period it was about twice the demand. During the summer period the dissolved oxygen decreased through the Louisville area but in winter the reverse was true, resulting in larger amounts in the river immediately below the city than in the water entering the district. In both summer and winter there was approximately the same increase in the amount of oxygen demand between stations 598 and 611, but the decrease between stations 611 and 619 in winter was somewhat over twice the decrease between the same stations in summer. The data further indicate a slight decrease in ratio of dissolved oxygen to oxygen demand through the district in the summer period, due to the decrease in dissolved oxygen, but practically no change in ratio is indicated during the winter period.

Finally, comparing the results of the 1914–15 and 1930–31 investigations, at Louisville (Table No. 30 (A and B) the data suggest that in the summer period of pool stage, 1930, the dissolved oxygen in the river was approximately 70 per cent of that present in 1914. The oxygen demand above and below the city in 1930 was also about 70 per cent of that in 1914, but within the zone of pollution the demand in the summer of 1930 was probably higher than that of the summer of 1914. Changes in the oxygen relationships resulted in a slightly lower ratio of dissolved oxygen to oxygen demand at Louisville during summer pool stage in 1930 than in 1914.

The winter period of 1914–15 showed greater amounts of dissolved oxygen and oxygen demand than either the winter or the spring period of open channel in 1930–31. In the winter period of pool stage, 1930–31, the amount of oxygen demand was approximately 5 per cent and in the spring period from 25 to 35 per cent of that present in the winter of 1914–15.

The ratio of dissolved oxygen to oxygen demand was greater in both the winter season of pool stage and the spring period of open channel in 1930–31 than in 1914–15.

Of greatest significance in this section of the stream is the marked reduction in the amount of oxygen demand carried by the river in 1930–31 as compared to that of 1914–1916, changes very comparable to those already observed in the river at Cincinnati.

Comparisons of the oxygen relationships in the Ohio River at Cincinnati and Louisville during the past and present investigations indicate that during the winter months of comparable channel and stream flow conditions but little change in the sanitary condition of the stream has taken place in the vicinity of these metropolitan areas during the 15 years between 1914–15 and 1929–1931. In general both the dissolved oxygen and the oxygen demand in the stream appear to be lower now than formerly, the greater reduction in oxygen demand tending to produce a greater amount of available oxygen in the river at the present time.

In the summer period of decreased stream flow and pool stages, but little change in sanitary conditions is indicated outside of the zones of sewage pollution. Continued pool stage in summer, as a result of canalization, has permitted sedimentation to take place behind the navigation dams in the vicinity of the sewer outlets, and the oxygen requirements of these deposits, at times of high-water temperatures, place an additional burden on the oxygen resources of the stream within the zone of pollution, reducing materially the amount of dissolved oxygen in the river. The principal effect of canalization therefore has been to move the point at which critical oxygen conditions may be approached from a considerable distance below the major sources of pollution, upstream, into the zone of sewage contamination.

SECTION VI

BACTERIOLOGICAL STUDIES

BASIC TABULATIONS

Observations of the bacterial content of the water from the 15 regular sampling stations on the Ohio River from Cincinnati to Louisville were made triweekly in the majority of cases, and twice each week in the remainder. The following tabulation shows the periods during which samples were collected from various sections of the river and the total number of samples analyzed:

Sampling stations	Period of sample collection	Number of samples collected
Stations 461 to 533, inclusive	November, 1928, to December, 1930, inclusive	1,268
Stations 548 and Kentucky River	June to December, 1929, inclusive	120
Stations 596 to 634, inclusive	May, 1930, to May, 1931, inclusive	448
Total bacteriological samples collected		1,836

Routine bacteriological examinations consisted of standard plate counts on agar, incubated at 37° C. for 24 hours, as well as an estimate of the number of organisms of the coli-aerogenes group, by means of fermentation tests in lactose broth with portions of the water sample in geometric series.

Results of the daily bacteriological observations are presented in the form of basic tabulations showing the monthly averages, for each sampling station, during every month of the investigation. For purposes of comparison the basic data are arranged in tables, as follows:

(1) Summary for each station, during all months when samples were collected, of the means of the daily bacteriological observations, as well as the mean monthly river discharge and water temperature, together with monthly means of the bacteriological observations expressed in terms of "quantity units." [38]

(2) Summary of the bacteriological observations at all stations in terms of quantity units of 37° C. and coli-aerogenes organisms grouped as seasonal averages with reference to channel conditions.

Table No. 31 summarizes the bacteriological and related data at each of the 15 regular sampling stations by months. Stations are arranged in consecutive order passing downstream, the results from tributaries being inserted between points where they join the main stream.

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[38] For comparative studies of bacterial pollution it is essential to consider actual numbers of bacteria as well as their concentration. Numbers of bacteria can best be expressed in terms of a unit combining time, volume and bacterial concentration. Such a unit has been designated as the "quantity unit" and may be defined as the product of 1 cubic foot discharge per second and a concentration of 1,000 bacteria per cubic centimeter. Therefore the number of quantity units of bacteria in a stream is:

$$\frac{\text{Discharge (sec.-ft.)} \times \text{Bacteria (per c. c.)}}{1000}$$

Quantity units of bacteria may be converted into actual numbers per unit of time by suitable conversion factors; as, for example, bacteria per day equals quantity units times the factor 2,446,588,800,000, or cubic centimeters per cubic foot (28,317), times seconds per day (86,400) times 1,000. The quantity unit is directly proportional to the total number of bacteria present and is much less cumbersome to use.

TABLE No. 31.—*Summary of bacteriological observations by stations, in terms of concentration and "quantity units" (bacteria per cubic centimeter multiplied by discharge in thousands of second-feet), monthly means and seasonal averages at each station*

SAMPLING STATION 461.—OHIO RIVER ABOVE CINCINNATI, 1 MILE ABOVE MOUTH OF LITTLE MIAMI RIVER

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	152,100	8.8	4,200	72	640,000	10,717
December	190,400	2.5	1,700	44	324,000	[illegible]
1930						
January	195,100	2.9	1,800	61	345,700	11,718
February	120,900	4.1	2,300	179	299,270	[illegible]
March	299,300	6.4	1,100	26	328,000	[illegible]
April	97,400	11.6	1,400	28	136,300	[illegible]
May	34,600	20.1	3,100	24	107,200	[illegible]
June	22,000	22.9	2,000	9	44,000	48
July	6,500	26.9	2,000	.6	13,000	4
August	5,830	25.4	1,200	2	7,000	8
September	4,600	22.4	700	3	3,200	14
October	3,300	16.1	1,100	2	3,600	7
November	5,400	9.2	100	.1	600	1
December	12,510	2.8	120	2	1,400	25

AVERAGES

Year 1930	50,200	14.5	1,600	58	80,200	[illegible]
November to April, inclusive	146,700	6.6	2,100	71	307,170	[illegible]
May to November, inclusive	11,040	20.7	1,600	5	25,500	150

SAMPLING STATION—LITTLE MIAMI RIVER, ONE-HALF MILE ABOVE MOUTH

Month	Mean discharge second-feet	Mean temperature °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	3,540	7.7	13,000	460	46,020	1,628
December	2,150	3.1	11,500	87	26,870	277
1930						
January	5,920	3.5	5,900	180	33,450	1,068
February	3,960	5.4	10,500	72	41,700	285
March	2,330	6.0	6,500	344	15,150	801
April	1,200	12.5	10,500	180	12,600	216
May	300	19.5	92,000	600	28,430	180
June	150	25.1	240,000	2,013	36,100	300
July	62	26.5	1,800,000	50,300	147,600	3,148
August	62	25.4	1,200,000	17,710	78,400	1,098
September	142	21.7	700,000	6,000	99,400	852
October	65	13.6	550,000	4,900	35,750	319
November	78	8.6	44,000	3,314	3,420	259
December	95	1.8	40,500	5,200	3,800	517

AVERAGES

Year 1930	1,180	12.7	390,000	4,576	46,420	668
November, 1929, to April, 1930, inclusive	3,300	6.4	9,050	231	30,780	706
May to November, 1930 inclusive	131	19.2	661,000	8,677	64,450	700

TABLE No. 21.—*Summary of bacteriological observations by stations, etc.*

SAMPLING STATION—LICKING RIVER, ABOUT 3 MILES ABOVE MOUTH

Month	Mean discharge second-feet	Mean temperature °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	6,170	9.6	3,400	180	[illegible]	1,319
December	3,600	2.9	5,900	200	28,070	794
1930						
January	7,810	4.2	2,700	19	21,080	148
February	8,980	5.5	3,600	33	33,180	286
March	4,740	7.4	900	21	4,270	[illegible]
April	1,680	13.8	3,100	140	5,670	[illegible]
May	780	21.1	10,500	160	7,380	[illegible]
June	163	26.6	66,000	320	6,080	[illegible]
July	19	27.3	130,000	2,021	2,470	[illegible]
August	16	25.2	130,000	3,000	2,080	[illegible]
September	14	24.8	450,000	4,263	6,300	[illegible]
October	6	15.9	100,000	1,300	900	[illegible]
November	13	9.8	21,000	307	400	[illegible]
December	45	3.7	50,000	730	2,056	26

AVERAGES

Year 1930	2,080	15.4	84,000	1,011	7,080	96
November, 1929, to April, 1930, inclusive	5,670	7.4	3,300	99	18,230	440
May to November, 1930, inclusive	124	21.2	134,000	1,586	4,010	46

SAMPLING STATION 475.—OHIO RIVER IMMEDIATELY BELOW CINCINNATI

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	165,600	10.3	22,500	290	3,678,300	43,464
December	127,500	2.6	7,000	321	892,500	40,928
1930						
January	205,300	3.3	4,500	163	924,720	33,467
February	138,800	4.2	5,700	46	791,160	6,386
March	210,400	6.4	3,600	149	757,440	31,330
April	100,400	12.3	16,300	425	1,637,400	42,670
May	35,600	20.3	68,000	760	2,436,400	26,930
June	23,000	26.7	160,000	1,330	3,680,000	30,707
July	6,930	27.0	170,000	3,775	1,178,100	26,161
August	3,920	25.2	200,000	2,316	784,000	9,075
September	4,830	23.7	98,000	1,600	473,340	7,730
October	3,300	16.1	220,000	4,150	729,200	13,944
November	5,570	9.7	160,000	14,410	891,200	80,264
December	12,610	3.0	45,000	486	567,450	6,128

AVERAGES

Year, 1930	62,590	14.6	96,000	2,460	1,298,270	29,080
November to April, inclusive	157,670	6.5	10,300	227	1,465,280	32,580
May to November, inclusive	11,980	20.5	154,000	4,041	1,457,460	27,080

TABLE No. 31.—*Summary of bacteriological observations by stations, etc.*—Contd.

SAMPLING STATION 482.—OHIO RIVER, 0.7 MILE BELOW DAM NO. 37 (FERNBANK)

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	153,700	8.6	16,000	246	3,455,300	40,[illegible]
December	137,700	2.5	6,700	213	442,[illegible]	27,300
1930						
January	265,900	2.9	4,600	75	936,[illegible]	15,900
February	130,100	4.3	4,800	206	905,100	28,514
March	253,[illegible]	6.4	4,900	103	950,[illegible]	23,[illegible]
April	160,050	12.5	20,050	146	3,042,300	14,[illegible]
AVERAGES						
November, 1929, to April, 1930, inclusive	157,970	6.4	9,000	174	1,262,300	26,000

SAMPLING STATION 488.—OHIO RIVER, JUST ABOVE MOUTH OF GREAT MIAMI RIVER

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	104,000	9.1	6,800	180	1,550,000	28,[illegible]
December	127,900	4.6	2,500	280	319,730	35,613
1930						
January	206,200	5.5	2,700	100	586,740	20,620
February	130,300	5.4	3,300	49	420,080	6,[illegible]
March	211,100	6.4	3,800	154	802,100	32,[illegible]
April	[illegible]0,800	11.6	18,000	247	1,814,400	24,900
May	2[illegible],700	19.6	110,000	900	2,987,000	22,120
June	25,100	22.6	65,000	200	1,965,500	11,500
July	5,600	25.6	47,000	20	236,640	271
August	3,600	23.4	28,300	59	104,150	163
September	4,800	23.1	17,000	235	82,400	1,140
October	3,370	15.7	11,800	327	38,700	1,082
November	5,300	10.5	25,000	426	128,730	2,261
December	12,630	5.6	34,500	480	426,420	3,040
AVERAGES						
Year 1930	62,900	14.9	32,000	206	887,041	11,000
November, 1929, to April, 1930, inclusive	145,200	7.1	6,000	166	915,400	26,000
May to November, 1930, inclusive	11,000	20.6	[illegible],000	254	940,220	6,970

TABLE No. 31.—*Summary of bacteriological observations by stations, etc.*—Contd.

SAMPLING STATION—GREAT MIAMI RIVER (AT MOUTH) IN MIDSTREAM

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	4,560	7.7	23,000	680	105,040	3,100
December	8,730	3.4	12,000	440	104,760	3,840
1930						
January	26,800	4.5	7,700	55	206,360	1,474
February	19,670	3.4	8,700	464	171,130	9,130
March	6,680	6.3	12,000	262	80,160	1,750
April	2,570	12.4	9,300	58	23,900	149
May	1,570	20.7	25,000	11	39,250	17
June	1,260	24.6	48,500	8	61,110	10
July	720	25.3	22,400	6	16,130	4
August	642	25.6	17,000	6	10,910	4
September	576	21.3	16,000	15	9,220	12
October	740	14.4	6,800	3	5,030	2
November	665	9.5	2,600	7	1,730	5
December	755	4.0	3,700	180	2,790	136

AVERAGES

Month	Mean discharge second-feet	Mean temperature, °C.	On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
Year 1930	4,610	14.3	14,400	90	47,090	720
November, 1929 to April, 1930, inclusive	10,240	7.0	13,200	314	105,130	3,080
May to November, 1930, inclusive	901	19.9	18,600	8	20,100	8

SAMPLING STATION 492.—OHIO RIVER, 2.6 MILES BELOW MOUTH OF GREAT MIAMI RIVER

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	168,800	9.6	7,600	90	1,286,000	15,193
December	136,700	4.6	3,500	226	478,450	30,894
1930						
January	232,300	2.3	2,900	78	673,700	18,171
February	149,900	4.9	3,000	36	449,700	5,396
March	218,000	6.0	5,000	145	1,090,000	31,610
April	104,300	11.7	15,500	264	1,616,650	27,540
May	37,400	19.7	72,000	2,690	2,692,800	100,606
June	24,400	23.6	60,000	400	1,464,000	9,760
July	7,680	26.8	25,500	93	195,840	717
August	4,610	25.4	14,000	58	64,540	267
September	5,730	22.9	9,200	250	52,720	1,430
October	4,120	16.6	6,800	50	28,020	206
November	6,280	10.5	19,500	426	122,460	2,675
December	13,400	5.6	30,700	290	411,380	3,886

AVERAGES

Month	Mean discharge second-feet	Mean temperature, °C.	On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
Year 1930	67,400	14.7	22,700	370	747,930	16,980
November, 1929, to April, 1930, inclusive	168,450	7.0	6,300	140	909,430	21,470
May to November, 1930, inclusive	12,880	20.5	30,000	567	660,060	16,026

TABLE No. 31.—*Summary of bacteriological observations by stations, etc.*—Contd.

SAMPLING STATION 503.—OHIO RIVER, JUST ABOVE RISING SUN, IND., AND 1 MILES BELOW DAM NO. 38

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	170,200	9.2	9,600	330	1,633,920	56,166
December	137,800	5.3	5,200	270	716,560	37,206
1930						
January	234,900					
February	151,100	5.6	6,300	180	951,930	27,198
March	219,800	6.3	4,200	67	923,160	14,727
April	105,200	11.3	17,500	153	1,841,000	16,096
May	37,700	19.8	59,000	1,666	2,224,300	62,808
June	24,600	24.0	39,000	370	959,400	9,102
July	7,740	26.0	8,800	8	68,110	62
August	4,650	25.0	14,500	5	67,430	23
September	5,780	22.6	6,100	6	35,260	35
October	4,160	15.2	1,400	7	5,820	29
November	6,330	9.0	3,100	129	19,620	817
December	13,500	3.9	27,000	403	364,500	5,441
AVERAGES						
Year 1930 [1]	67,960	15.3	17,000	271	678,230	12,380
November, 1929, to April, 1930, inclusive	169,830	7.2	8,600	200	1,213,310	30,280
May to November, 1930, inclusive	12,990	20.2	19,000	311	482,880	10,350

[1] 11 months only, February to December, inclusive.

SAMPLING STATION 535.—OHIO RIVER, JUST ABOVE VEVAY, IND., AND 5.4 MILES BELOW DAM NO. 39

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1929						
November	170,900	9.9	4,800	172	820,320	29,395
December	138,400	3.8	3,800	260	525,920	35,984
1930						
January	236,000					
February	151,800	5.4	4,100	55	622,380	8,349
March	220,800	6.5	3,600	76	794,880	16,780
April	105,700	11.7	8,500	153	898,450	16,172
May	37,900	20.0	15,500	321	587,450	12,166
June	24,700	23.5	4,800	33	118,560	815
July	7,780	26.1	2,800	3	21,780	23
August	4,670	25.0	2,300	1	10,740	5
September	5,800	22.7	2,200	11	12,760	64
October	4,180	15.0	800	1	3,340	4
November	6,360	9.8	240	.6	1,530	4
December	13,600	4.1	5,100	32	69,360	435
AVERAGES						
Year 1930 [1]	68,270	15.4	4,200	62	285,575	4,980
November, 1929, to April, 1930, inclusive	170,600	7.5	5,000	143	732,390	21,340
May to November, 1930, inclusive	13,060	20.3	4,100	53	106,020	1,870

[1] 11 months only, February to December, inclusive.

TABLE No. 31.—*Summary of bacteriological observations by stations, etc.*—Contd.

SAMPLING STATION.—KENTUCKY RIVER, AT MOUTH, CARROLLTON, KY.

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1930						
June	285	25.7	28,500	670	8,120	101
July	183	26.3	4,200	14	640	2
August	168	23.5	67,000	10	16,360	2
September	115	22.3	11,000	11	1,270	1
October	125	16.3	2,500	2	310	0
November	202	9.4	450	0.4	90	0
December	310	3.7	2,600	4	510	1
AVERAGES						
June to November, 1930, inclusive	178	20.7	22,300	118	4,470	38

SAMPLING STATION 548.—OHIO RIVER AT BROOKSBURG, IND., 4.6 MILES BELOW THE MOUTH OF THE KENTUCKY RIVER

Month	Mean discharge second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1930						
June	25,000	25.0	425	6	10,630	160
July	7,940	26.4	6,000	12	47,640	95
August	4,860	25.1	4,700	8	22,840	30
September	5,920	23.0	1,300	1	7,700	6
October	4,310	16.0	1,200	.3	5,170	1
November	6,570	9.0	1,300	2	8,540	13
December	13,900	3.3	9,800	34	136,220	473
AVERAGES						
June to November, 1930, inclusive	9,100	20.8	2,500	5	17,090	51

SAMPLING STATION 598.—OHIO RIVER, ABOVE LOUISVILLE, KY., OPPOSITE WATER-WORKS INTAKE

Month	Mean discharge, second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hour	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1930						
May	41,700	20.1	1,300	20	54,210	834
June	25,300	24.0	375	2	9,490	51
July	8,040	27.7	950	2	7,640	16
August	4,920	27.4	3,300	110	16,240	541
September	6,000	25.0	1,200	3	7,200	18
October	4,360	18.5	1,900	2	8,280	9
November	6,650	11.3	1,000	.2	6,650	1
December	14,100	5.0	450	.5	6,350	7
1931						
January	21,600	1.9	1,200	4	25,920	86
February	58,500	4.0	4,400	24	257,400	1,404
March	79,800	4.9	7,500	25	498,500	1,995
April	226,100	8.8	12,500	285	2,828,260	64,439
May	125,500	16.3	7,000	115	878,500	14,433
AVERAGES						
Year May, 1930, to April, 1931	41,420	14.9	3,000	40	310,340	5,780
May, 1930, to November, 1930, inclusive	18,850	22.0	1,400	20	15,670	210
November, 1930, to April 1931, inclusive	67,790	6.0	4,500	56	603,510	11,320

TABLE No. 31.—*Summary of bacteriological observations by stations, etc.*—Contd.

SAMPLING STATION 605.—OHIO RIVER, OPPOSITE NEW ALBANY WATERWORKS INTAKE, ABOUT 1 MILE BELOW DAM NO. 41

Month	Mean discharge, second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hour	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1930						
May [1]	41, 700	21. 4	2, 100	30	87, 570	1, 251
June [1]	25, 300	24. 5	5, 800	132	146, 740	3, 340
July [1]	8, 040	27. 8	28, 000	250	225, 120	2, 010
August	4, 920	27. 5	23, 000	300	113, 160	1, 476
September	6, 000	25. 1	52, 000	450	312, 000	2, 700
October	4, 360	18. 4	57, 000	295	248, 520	1, 286
November	6, 650	10. 9	76, 000	933	505, 400	6, 204
December	14, 100	5. 4	23, 500	177	331, 350	2, 496
1931						
January	21, 600	1. 9	8, 400	26	181, 440	562
February	58, 500	3. 9	14, 000	19	819, 000	1, 112
March	79, 800	4. 4	6, 200	58	494, 760	4, 628
April	226, 100	9. 1	10, 500	47	2, 374, 050	10, 627
May	125, 500	16. 3	14, 000	445	1, 757, 000	55, 848
AVERAGES						
Year May, 1930, to April, 1931, inclusive	41, 420	15. 0	25, 500	226	486, 590	3, 140
May to November, 1930, inclusive	13, 850	22. 2	35, 000	341	234, 070	2, 010
November, 1930, to April, 1931, inclusive	67, 790	6. 0	23, 100	210	784, 330	4, 270

[1] Sample from north sampling point only.

SAMPLING STATION 624.—OHIO RIVER AT KOSMOSDALE, KY., 20 MILES BELOW DAM NO. 41

Month	Mean discharge, second-feet	Mean temperature, °C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hour	Coli-aerogenes estimated	On agar at 37° C. 24 hours	Coli-aerogenes estimated
1930						
May	41, 700	20. 3	10, 000	287	417, 000	11, 968
June	25, 300	23. 8	5, 600	65	141, 680	1, 645
July	8, 040	27. 1	2, 300	63	18, 490	507
August	4, 920	27. 5	1, 800	29	8, 860	143
September	6, 000	24. 8	9, 100	400	54, 600	2, 400
October	4, 360	18. 2	8, 600	141	37, 500	615
November	6, 650	11. 3	21, 500	141	142, 980	938
December	14, 100	5. 0	26, 000	70	366, 600	987
1931						
January	21, 600	1. 8	26, 000	145	561, 600	3, 132
February	58, 500	3. 9	28, 500	154	1, 667, 250	9, 009
March	79, 800	4. 3	9, 600	205	766, 080	16, 359
April	226, 100	9. 1	20, 500	125	4, 635, 050	28, 263
May	125, 500	16. 0	14, 000	230	1, 757, 000	28, 865
AVERAGES						
Year May, 1930, to April, 1931, inclusive	41, 420	14. 8	18, 130	152	734, 810	6, 310
May to November 1930, inclusive	13, 850	21. 9	8, 400	161	117, 300	2, 600
November, 1930, to April 1931, inclusive	67, 790	6. 0	22, 000	140	1, 356, 590	9, 780

Bacterial concentration is quite sensitive to changes in water temperature and to times of flow from sources of pollution, which in turn are influenced by the rate of stream discharge and channel conditions. It has been found advisable, therefore, to present for comparison the bacteriological findings grouped: (a) For a period representing open-river conditions, when the navigation dams were down and times of flow in the river relatively short, and (b) for a period of pool stage when the dams were raised, forming a series of pools along the entire river, increasing times of flow very materially.

TABLE No. 32.—*Seasonal averages of bacteriological observations at each sampling station in terms of quantity units (bacteria per cubic centimeter multiplied by discharge in thousands of second-feet)*

Sampling station	Mean discharge, second-feet	Mean water temperature, ° C.	Bacteria per cubic centimeter		Quantity units of bacteria	
			On agar at 37° C. 24 hours	Coli-aerogenes estimated	On agar at 37° C., 24 hours	Coli-aerogenes estimated
A. WINTER SEASON, OPEN CHANNEL, NOVEMBER, 1929, TO APRIL, 1930, INCLUSIVE						
461	148,700	6.4	2,100	71	307,170	10,000
Little Miami	3,300	6.4	9,600	321	30,760	706
Licking	5,670	7.4	3,300	99	18,220	469
475	157,670	6.5	10,300	227	1,483,290	32,880
482	157,970	6.4	9,600	174	1,362,300	26,590
488	158,220	7.1	6,600	168	918,460	25,030
Great Miami	10,240	7.0	12,200	314	106,130	2,560
492	168,450	7.0	6,200	140	939,420	21,470
503	169,830	7.2	8,600	200	1,213,310	30,280
535	170,600	7.5	5,000	148	732,390	21,340
B. SUMMER SEASON, POOL STAGE, MAY TO NOVEMBER, 1930, INCLUSIVE						
461	11,640	20.7	1,600	5	25,950	130
Little Miami	131	19.2	661,000	5,677	64,450	790
Licking	124	21.2	134,000	1,598	4,010	46
475	11,890	20.8	154,000	4,041	1,457,460	27,560
488	11,930	20.6	46,000	354	940,320	6,970
Great Miami	951	19.9	18,600	8	20,500	8
492	12,890	20.5	30,000	567	660,060	16,524
503	12,990	20.2	19,000	311	482,850	10,350
535	13,060	20.3	4,100	53	106,020	1,870
Kentucky [1]	178	20.7	22,300	118	4,470	33
548 [1]	9,100	20.8	2,500	5	17,090	51
598	13,850	22.0	1,400	20	15,670	210
605	13,850	22.2	35,000	341	234,070	2,610
624	13,850	21.9	8,400	161	117,300	2,600

[1] Average of 6 months, June to November, 1930, inclusive.

In the present investigation the winter and spring months, November, 1929, to April, 1930, inclusive, have been taken as representative of open-river conditions during which the average stream flow was 158,000 second-feet at Cincinnati, varying between 100,000 and 210,000 second-feet, giving an average time of flow between Cincinnati and Louisville of 53 hours. During this period the average water temperature was 7.0°, the monthly means varying between 6.4° and 7.5° C. The 7-month period May to November, 1930, has been taken as indicative of pool conditions with stream flows past Cincinnati averaging only 11,900 second-feet and varying between 3,360 and 35,000 second-feet, giving an average estimated time of flow from Cincinnati to Louisville of over 800 hours. In this period water temperatures averaged 21.0° C., the monthly means varying between 20.2° and 22.2° C.

The bacteriological results expressed as seasonal averages for these two extremes of river conditions are presented in terms of quantity units in Table No. 32.

BACTERIAL POLLUTION OF THE OHIO RIVER

The general extent of the bacterial pollution of the Ohio River, within and below the Cincinnati and Louisville metropolitan areas, may be ascertained from the following yearly and seasonal averages of the concentration of organisms growing on agar at 37° C. (Table No. 33.)

TABLE NO. 33.—*Yearly and seasonal averages of bacteria growing on agar at 37° C., at sampling stations on the Ohio River between Cincinnati and Louisville*

Sampling station	Location	Average concentration of bacteria per cubic centimeter		
		Year, January to December, 1930	Winter, open river, November, 1929, to April, 1930	Summer, pool stage, May to November, 1930
461	Above Cincinnati	1,500	2,100	1,600
475	Below Cincinnati	96,000	10,300	184,000
486	Above Miami River	32,000	6,600	46,000
492	Below Miami River	22,700	6,200	30,000
506	Above Rising Sun	[1] 17,000	[2] 8,600	19,000
535	Above Kentucky River	[1] 4,200	[2] 5,000	4,100
548	Below Kentucky River			[3] 2,500
566	Above Louisville			1,400
606	At Louisville			35,000
624	Below Louisville			8,400

[1] February to December, inclusive. [2] January omitted, no data. [3] June to October, inclusive.

The concentration of bacteria, as indicated in Table No. 33, tends to increase within the zones of sewage pollution at Cincinnati and Louisville, reaching a maximum below the sewer outlets, and then to decrease rapidly in the section of the water course which receives but little additional contamination. In the period of lower water temperatures and unobstructed flow, the average bacterial concentration within and below the zones of sewage pollution appears to be less than during the period of high water temperature and pool stage. In the period of open channel and shorter times of flow, a slight increase in bacterial concentration, following the initial decrease below the sewers, is indicated below the Great Miami River. Based on yearly averages, the concentration of bacteria in the Little Miami and Kentucky Rivers is greater than the concentration in the main river, near their respective points of confluence, while the concentration of bacteria in the Licking and Great Miami Rivers is less than the concentration in the main stream. The actual numbers of the bacteria contributed by these tributaries are in general less than those present in the main stream at their points of entrance, and their effect is that of dilution.

SEASONAL CHANGES IN BACTERIAL CONTENT

A more direct comparison of the seasonal changes in bacteria is afforded by the estimates of the quantity units of bacteria present in the stream. For purpose of comparison the average number of quantity units of both 37° C. and coli-aerogenes organisms, during the period of pool stage and high water temperatures, and those for the winter period of low water temperature and open-river conditions, have been summarized for the sampling stations in the vicinity of Cincinnati in the following tabulation. (Table No. 34.)

TABLE No. 34.—*Seasonal averages of quantity units of bacteria present in the Ohio River at sampling stations between the Little Miami and Kentucky Rivers*

Station	Location	Average quantity units of bacteria			
		37° C.		Coli-aerogenes	
		Summer	Winter	Summer	Winter
461	Above Cincinnati	26,000	307,200	130	10,000
Little Miami	Mouth	64,500	30,760	790	710
Licking	do	4,000	18,200	46	470
475	Below Cincinnati	1,457,500	1,483,300	27,580	32,890
488	Above Great Miami	940,300	918,500	6,970	25,000
Great Miami	Mouth	20,500	106,100	8	2,560
492	Below Great Miami	660,100	929,400	16,550	21,470
503	Rising Sun	482,900	1,212,300	10,350	30,280
535	Vevay	106,000	732,400	1,870	21,340

Table No. 34 shows that the number of quantity units of both 37° C. and coli-aerogenes organisms were very much the same immediately below Cincinnati in both the winter period of open river and the summer period of pool stage. In the summer months the quantity units of bacteria were less at corresponding points below Cincinnati than in the winter period of open channel. During pool stage, times of flow are materially increased, so that a greater reduction in bacteria takes place in shorter distances along the river, the probable explanation of the greater reduction in bacteria between stations 475 and 535 during the summer period.

With the exception of the Little Miami River, in the summer period of pool stage, the contributions of actual numbers of bacteria by the tributaries are less than the number present in the main stream at their confluence. The Licking River, which enters the Ohio within the zone of sewage pollution, contributes on an average less than 1 per cent, in both summer and winter, of the bacteria present in the main stream at station 475. Contributions by the Great Miami River, are in winter, approximately 12 per cent or less and in summer 2 per cent or less of those of the main stream. At times of open channel the Little Miami contributes approximately 10 per cent of the 37° C. and 7 per cent of the coli-aerogenes organisms present in the Ohio River above its mouth. During pool stage the contributions of 37° C. organisms by this tributary are nearly 2.5 times and of coli-aerogenes organisms over 6 times those of the main stream.

It will be noted that in the winter period of open channel and rapid flow, there was an apparent increase in both 37° C. and coli-aerogenes organisms below the Great Miami River. In summer, with increased times of flow between the sources of pollution and the tributary, no such increase is indicated.

BACTERIAL POLLUTION OF THE OHIO RIVER IN THE VICINITY OF THE WATERWORKS INTAKES, 1914–1916 AND 1929–1931

Monthly averages of the concentration of 37° C. and coli-aerogenes organisms, in so far as they are available during the 1914–1916 and 1929–1931 surveys at the Cincinnati and Louisville waterworks intakes (stations 461 and 598, respectively) have been tabulated in Table No. 35. Averages representative of the concentration of bacteria at the intakes, during periods of unobstructed flow and pool stage, have been included for comparison with the general average of bacterial concentration irrespective of river conditions. The winter and spring months are usually those of open channel conditions, summer and fall months of pool stage conditions.

The data of Table No. 35 indicate a very marked correlation between the counts at these two waterworks intakes, showing that in general they are similarly affected by season and stream-flow conditions. The higher counts occurring more frequently at Louisville than at Cincinnati are undoubtedly the result of the sewage and wastes from the Cincinnati metropolitan district, since the other factors operating between these points (time and dilution) tend toward a reduction in bacterial concentration.

General averages of bacterial concentration at the waterworks intakes indicate but little change in the number of bacteria in the river between the first investigation in 1914–1916 and the present investigation of 1929–1931. Comparing the months of open river with pool stage conditions, the data suggest, during both investigations, somewhat higher bacterial concentrations at the waterworks intakes at times of unobstructed flow than at pool stage. At the Cincinnati intake, under all river conditions, the concentration of 37° C. organisms was slightly greater in 1929–30 than in 1914–1916. The average concentration of coli-aerogenes organisms, irrespective of river conditions, and the concentrations at times of pool stage, is lower during the present investigation; but the concentration during periods of unobstructed flow in 1929–30 was nearly twice that of 1914–1916. Changes in conditions at the Louisville waterworks intake were very similar to those of Cincinnati, the data indicating an average concentration of 37° C. organisms and the concentration during pool stages slightly greater at present than in the past, but with about three times as many 37° C. organisms present at the intake in 1930–31, at times of unobstructed flow, than during 1914–1916. The average concentration of coli-aerogenes organisms and the concentration during pool stage was less in 1930–31 than in 1914–1916, but at times of unobstructed flow in the river during 1930–31 the concentration of coli-aerogenes organisms at the Louisville intake was over twice that of 1914–1916.

TABLE No. 35.—*Comparison of monthly mean bacterial counts at stations 461 (Cincinnati) and 598 (Louisville) during the years 1914–1916 and 1929–1931. Data arranged in order of magnitude of counts at station 461 with counts for corresponding month at station 598*

Years 1914-1916				Years 1929-1931			
37° C. organisms		Coli-aerogenes organisms		37° C. organisms		Coli-aerogenes organisms	
461	598	461	598	461	598	461	598
3,840	4,500	137	102	....	12,500	....	285
3,630	2,400	121	86	....	7,500	....	115
3,420	2,780	107	30	....	7,000	....	35
[1] 3,270	[1] 700	73	47	....	[1] 4,400	....	34
3,150	2,810	66	71	....	[1] 1,200	....	4
[1] 3,090	[1] 5,160	65	65	4,300	....	179	....
2,940	4,800	61	11	[1] 3,100	[1] 1,300	70	....
2,880	4,000	61	128	[1] 2,300	....	61	....
2,420	4,870	60	73	[1] 2,000	[1] 900	55	....
2,300	2,880	51	47	[1] 2,000	[1] 375	38	....
2,190	4,800	50	85	[1] 1,900	[1] 3,300	34	20
2,110	3,220	49	86	1,800	....	23	....
[1] 2,080	[1] 3,360	41	36	1,700	....	3	3
2,000	3,070	41	44	1,400	....	2	110
1,880	4,200	34	113	1,100	....	2	2
1,530	3,450	28	86	[1] 1,100	[1] 1,900	2	2
1,300	4,900	27	107	[1] 700	[1] 1,200	3	1
1,350	2,240	26	109	[1] 180	[1] 1,000	1	2
[1] 1,290	[1] 506	25	69	[1] 130	[1] 450	0	0
[1] 1,260	[1] 1,250	24	102				
[1] 1,160	[1] 800	20	32				
1,100	4,500	20	30				
[1] 940	[1] 4,100	19	97				
854	2,780	19	16				
704	2,000	19	78				
690	3,250	19	29				
[1] 661	[1] 800	17	31				
660	2,800	13	6				
560	543	12	61				
[1] 477	[1] 800	11	36				
440	2,730	7	1				
[1] 400	[1] 303	5	5				
300	2,780	5	37				
[1] 190	[1] 586	5	10				
160	220	2	4				
[1] 120	[1] 124	1	11				

AVERAGES

[2] 1,600 [3] 1,800 [1] 1,100	2,600 3,200 1,500	37 46 14	52 62 33	1,700 2,100 1,400	3,300 9,000 1,600	22 71 5	46 142 17

[1] Months of pool stage. [2] General average. [3] Months of open channel.

These data appear to indicate that with comparable conditions of unobstructed flow in the river during 1914–1916 and 1929–1931 at the Cincinnati and Louisville waterworks intakes, a slight normal increase in pollution has taken place. Canalization, by increasing times of flow from upstream sources of pollution and allowing natural purification agencies longer times in which to act, decreased the bacterial load at the waterworks intakes during pool conditions, more than offsetting the indicated normal increase in pollution, so that the concentration of coli-aerogenes organisms at the present time of pool stages is less than at the time of the previous survey.

The data of Table No. 35 indicate, from the general averages of the coli-aerogenes determinations, an index of approximately 3,300 and 4,600 per 100 cubic centimeters, at the Cincinnati and Louisville intakes, respectively.

According to Streeter [17] the maximum degree of raw water pollution in the Ohio River, as measured in terms of coli-aerogenes index, consistent with the production of effluents, by various methods of treatment, which conform to the revised Treasury Department standard (about 1 coli-aerogenes group organism per 100 cubic centimeters) is approximately as follows: Chlorination alone 80 coli-aerogenes organisms per 100 cubic centimeters; coagulation, sedimentation, rapid sand filtration (without chlorination) 80, with post chlorination 6,000, and with prechlorination and postchlorination 20,000 coli-aerogenes organisms per 100 cubic centimeters. Coagulation, double stage sedimentation, rapid sand filtration and postchlorination, 50,000 coli-aerogenes organisms per 100 cubic centimeter.

The raw-water maximum is a mean condition, defining the limiting degree of raw-water pollution which the average plant of the type studied might be expected to tolerate, consistent with attaining the objective stated, under normal conditions. Some individual plants, particularly those containing highly elaborated features, such as double-stage sedimentation or double filtration, would be expected, on the basis of the observations, to purify successfully raw waters more highly polluted than above indicated. Others, less highly elaborated or skillfully operated, might be unable to meet the raw water condition.

The average indicated coli-aerogenes index in 1929–1931, of 3,300 and 4,600 per 100 cubic centimeters at the Cincinnati and Louisville intakes, respectively, and the index of 500 and 1,700 per 100 cubic centimeters during periods of pool stage, fall below the theoretical figure of 5,000 per 100 cubic centimeters and, during a considerable portion of the year, plants of the type of those in use at Cincinnati and Louisville should have but little difficulty in producing a chlorinated effluent consistent with the bacteriological standard. During the months of unobstructed flow in the river the coli-aerogenes index of 7,100 and 14,200 per 100 cubic centimeters at Cincinnati and Louisville, respectively, suggests that the raw-water pollution is considerably greater than the theoretical maximum consistent with the production of an effluent by the customary standard methods of water treatment; coagulation, sedimentation, filtration and chlorination, which will consistently meet the Treasury Department standard, and at such times more elaborate methods of purification or careful operation are required.

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[17] Studies of the effect of water purification processes. H. W. Streeter. Public Health Bulletin No. 172.

In addition to Cincinnati and Louisville, two other communities, Aurora and New Albany, Ind., obtain their water supplies from the Ohio River within the section under observation. Aurora, located at Mile 495, is approximately 20 miles below the last of the Cincinnati sewers, or, in terms of flow, depending upon channel conditions, from 7.0 to 170.0 hours below the last of the sewer outlets. While no data are available representative of conditions in the river opposite the waterworks intake, conditions at station 492, three miles above, are in general indicative of the sanitary quality of the water at the Aurora intake. The following tabulation summarizes the bacteriological observations at station 492 during the 1914–1916 and the 1929–30 investigations and shows the average concentration of 37° C. and coli-aerogenes organisms, irrespective of channel conditions, also the concentration at times of open river and pool conditions.

Concentration of bacteria, per cubic centimeter, at station 492 during 1914–1916 and 1929–30

River condition	1914–1916		1929–30	
	37° C. organisms	Coli-aerogenes organisms	37° C. organisms	Coli-aerogenes organisms
Open river	25,600	598	6,200	140
Pool stage	54,100	1,324	30,000	567
Average conditions	36,000	850	22,700	299

In both 1914–1916 and 1929–30 the concentration of 37° C. and coli-aerogenes organisms was higher during the months of pool stage than during open channel, also the concentration in 1929–30 was consistently less than that of 1914–1916. Although the present bacterial content of the raw water at Aurora is high, with seasonal averages varying from 14,000 to 56,700 per 100 cubic centimeters and with a daily index probably at times as high as 100,000 per 100 cubic centimeters, the normal operation of the Aurora plant, which includes prechlorination, is sufficient to produce a safe water supply.

New Albany is located at Mile 604, opposite some and below other sewer outlets from the Louisville metropolitan area. A sampling station was maintained opposite the waterworks intake throughout the present investigation but no data are available in 1914–1916 for comparison with the present findings. The results of the present study indicate an average concentration of coli-aerogenes organisms in the river at the intake of 22,600 per 100 cubic centimeters, varying between 21,000 per 100 cubic centimeters, at times of unobstructed flow, and 34,100 per 100 cubic centimeters, during pool stage. Although the raw water at the New Albany waterworks intake is seriously polluted, a long period of presettling, approximately five days, and prechlorination, seems to be sufficient to reduce the bacterial load to the extent that normal treatment, consisting of coagulation and sedimentation, filtration and postchlorination, will produce a safe water, and it has been stated that no particular difficulty was encountered in the operation of the plant during the period of lowest stream flow in the Ohio River.

RELATION OF BACTERIAL POLLUTION TO THE CONTRIBUTING SEWERED POPULATION

In Table No. 36 there have been assembled the calculated average monthly changes in bacteria, expressed in terms of quantity units and corrected for tributary inflow, between stations 461 and 475, above and below, respectively, the Cincinnati metropolitan area. The calculated bacterial changes have also been expressed as the per capita contribution of quantity units of 37° C. and coli-aerogenes organisms based on a total estimated sewered population of 601,000 contributing sewage to the river between these points. Seasonal averages are included indicating the changes in bacteria during a winter period of open channel and a summer period of pool stage.

The seasonal averages of changes in quantity units of bacteria due to the sewered population of Cincinnati and vicinity appear to be very similar despite the entirely different conditions of channel and stream flow during the two periods. In the winter season of open river conditions, with water temperatures averaging 7° C., the mean stream discharge, 157,700 second-feet, and the time of flow through the metropolitan area of 5.3 hours, the daily per capita contribution of 37° C. and coli-aerogenes organisms was 1.860 and 0.0420 quantity units, respectively; numbers slightly less than the per capita contributions of 2.255 and 0.0440 quantity units of 37° C. and coli-aerogenes organisms, respectively, during the summer period of pool stage, with average water temperatures of 21° C., mean stream flows of 11,900 second feet, and times of flow through the metropolitan district of 56.6 hours.

Monthly changes within each seasonal group, however, show considerable variation during periods when channel conditions, discharge and times of flow were fairly comparable. During open channel conditions, with stream flows varying between 100,000 and 210,000 second-feet, producing times of flow through the metropolitan area varying from 4.6 to 6.1 hours, the changes in quantity units of 37° C. organisms varied from 427,600 to 2,964,400, and the quantity units of coli-aerogenes organisms from 5,380 to 38,500. Similarly, during the months of pool stage with discharges varying between 3,360 and 35,600 second-feet, giving times of flow from 9.6 to 101.4 hours through the district, changes in the quantity units of bacteria varied from 364,400 to 3,587,400 in the case of the 37° C. organisms and from 6,800 to 80,000 in the case of coli-aerogenes organisms.

TABLE No. 36.—*Average monthly and seasonal contributions of bacteria, in terms of quantity units and as the daily per capita contribution by the sewered population of the Cincinnati metropolitan area*

Month	Total increase in quantity units of bacteria between stations 481 and 475		Per capita contribution of quantity units of bacteria by the sewered population of the Cincinnati metropolitan area	
	37° C. organisms	Coli-aerogenes organisms	37° C. organisms	Coli-aerogenes organisms
1929				
November	2,964,440	28,920	4.900	0.0476
December	628,190	33,235	1.080	.0549
1930				
January	535,660	30,625	.885	.0541
February	427,630	[1] 5,383	.707	.0089
March	514,280	25,773	.848	.0426
April	1,709,770	28,487	2.810	.0626
Winter average	1,137,140	25,406	1.880	.0420
May	2,313,380	33,772	3.816	.0562
June	3,587,390	30,296	5.928	.0503
July	1,014,370	28,961	1.677	.0466
August	676,280	7,583	1.118	.0125
September	364,360	6,802	.602	.0112
October	688,250	12,689	1.136	.0225
November	886,380	80,056	1.465	.1332
Summer average	1,365,050	28,590	2.255	.0440

[1] Based on change station 461 to 482.

NOTE.—Sewered population of metropolitan area, estimated 601,000.

In comparison with similar calculations made with the data collected during the 1914–1916 survey (Table No. 37) the 1929–30 estimates of the per capita contribution of quantity units of bacteria are considerably lower in the summer period than in 1914–1916. In the winter period of 1929–30, slightly higher per capita contributions of 37° C. bacteria are indicated than in 1914–1916; while the contributions of coli-aerogenes organisms were very nearly the same in the winter period of both investigations.

TABLE No. 37.—*Seasonal changes in the numbers of bacteria added to the Ohio River by the sewered population of Cincinnati*

Added by Cincinnati	Year	Quantity units of bacteria per capita per day	
		37° C. organisms	Coli-aerogenes organisms
Summer	1914-1916	7.09	6.191
	1929-30	3.254	.0440
Winter	1914-1916	1.04	.037
	1929-30	1.089	.043

The marked variation in the bacterial contributions within the metropolitan area emphasize the effect of differences in river conditions and variations in stream flow, time, temperature, sedimentation, and scour, on the changes in the bacteria which are discharged into the watercourse.

Within the Louisville area the sampling stations located principally to show the condition of the river at the New Albany waterworks intake and the extent of pollution downstream during periods of unobstructed flow, are not entirely satisfactory to show the changes in bacterial contributions, in relation to the contributing population, at times of pool stage. A portion of the Louisville sewage enters the river above Dam No. 41 and additional amounts from Louisville, Jeffersonville, and New Albany enter between the dam and sampling station 605. Under most conditions of stream flow, an increase in the number of bacteria is indicated between stations 598 and 605, indicative probably of the pollution entering below the dam immediately above the sampling station and not the full effect of the pollution discharged into the pool above it, in which sedimentation undoubtedly takes place under normal conditions of stream flow.

In the periods of pool stage and increased times of flow, a decrease in bacteria is most always indicated between stations 605 and 624, showing that sedimentation and processes of natural stream purification more than offset the effects of the sewage and wastes added to the river between these points.

In the months of March, April, and May, 1931, more normal conditions of stream flow prevailed throughout the river and the changes in bacteria within the Louisville area are probably more nearly representative of the usual changes which occur in this section of the stream. During these months, changes of considerable magnitude are indicated in the 37° C. organisms but in the month of greatest increase in these bacteria the coli-aerogenes organisms decreased through the section.

In Table No. 38 there have been summarized the mean monthly changes in bacteria, expressed in terms of quantity units, between stations 598 and 624, above and below, respectively, the sewage pollution from the Louisville area. Seasonal averages have also been included, representing a summer and winter period of pool conditions and a spring period of open channel following an 11-month period of pool conditions.

TABLE No. 38.—*Average monthly and seasonal contributions of bacteria, in terms of quantity units, and as the daily per capita contribution by the sewered population of the Louisville metropolitan area*

Month	Total increase in quantity units of bacteria between stations 590-604		Per capita contribution of quantity units of bacteria by the sewered population of the Louisville metropolitan area	
	37° C. organisms	Coli-aerogenes organisms	37° C. organisms	Coli-aerogenes organisms
1930				
May	362, 790	11, 134	1. 273	0. 0391
June	132, 190	7, 594	. 464	. 0266
July	10, 850	491	. 038	. 0017
August	[1] 7, 360	[1] 396	[1] . 026	[1] . 0014
September	47, 400	2, 382	. 166	. 0084
October	29, 220	608	. 102	. 0021
November	136, 330	937	. 479	. 0033
Summer average	119, 800	2, 850	. 420	. 0100
December	360, 230	960	1. 263	. 0034
1931				
January	530, 660	3, 046	1. 861	. 0107
February	1, 409, 550	7, 605	4. 950	. 0267
Winter average	766, 800	3, 877	2. 690	. 0136
March	267, 500	14, 384	. 938	. 0504
April	1, 798, 800	[1] 36, 170	6. 340	[1] . 1269
May	875, 500	14, 430	3. 090	. 0506
Spring average	984, 960	14, 400	3. 453	. 0505

[1] Decrease in quantity units, omitted from average.

NOTE.—Sewered population of metropolitan area estimated, 285,000.

Changes in the bacteria (Table No. 38) fluctuate rather more consistently with the volume and time of flow during the period of pool stage, than the indicated changes in the upper section at Cincinnati. In general, the increases in bacteria became less with increasing times of flow between May and August, 1930, until in August the bacteria at the lower station, below the sewers, were less than in the water entering the area. With increasing volumes of flow, the increase in bacteria became greater until in the spring of 1931 the velocities had increased to such an extent that scour may have been a factor in the bacterial changes.

The per capita contribution of 37° C. and coli-aerogenes organisms by the sewered population increased from 0.420 and 0.0100 quantity unit, respectively, in the period of longest times of flow, to 3.453 and 0.0505 quantity units, respectively, in the months of shortest times of flow. In comparison with the calculated per capita contributions of quantity units of bacteria at the time of the previous investigation

(Table No. 39) those of the summer of 1930 were much lower than in the summer of 1914–1916. The 1930–31 winter and spring contributions of 37° C. organisms were several times greater and the 1930–31 winter and spring contributions of coli-aerogenes organisms less than those of the winter of 1914–1916. The 1931 spring contributions of 0.0505 quantity unit per capita approached more nearly those of the 1914–1916 winter contributions, 0.0789 quantity unit per capita.

TABLE NO. 39.—*Seasonal changes in the numbers of bacteria added to the Ohio River by the sewered population of Louisville*

Added by Louisville	Year	Quantity units of bacteria per capita per day	
		37° C. organisms	Coli-aerogenes organisms
Summer	1914–1916	6.475	0.1159
	1930–1931	.420	.0160
Winter	1914–1916	.3707	.0789
	1930–1931	2.696	.0130
Spring	1930–1931	3.453	.0505

Comparing the per capita contributions of bacteria at Louisville with those at Cincinnati, using the data of the present survey, the contributions in summer of both 37° C. and coli-aerogenes at Louisville were approximately one-fourth those from the Cincinnati area. Contributions of coli-aerogenes organisms in both the winter and spring periods at Louisville were less than the contributions from the Cincinnati district but the winter and spring contributions of 37° C. organisms at Louisville were in excess of those at Cincinnati.

These data still further emphasize the effect of variations in volume, velocity, and time of flow on the number of bacteria present in polluted sections of a watercourse.

COMPARISON BETWEEN THE BACTERIAL POLLUTION OF THE OHIO RIVER BELOW CINCINNATI AND LOUISVILLE IN 1914–1916 AND 1929–1931

Conditions below Cincinnati.—Data for a comparison of conditions in the Ohio River below Cincinnati during the past and present survey are available during a winter period as far downstream as theKentucky River and during a summer period as far downstream as Louisville. In the following tabulation (Table No. 40) the bacteriological results of the 1914–1916 and 1929–30 investigations have been assembled in terms of bacterial quantity units, as seasonal averages of 37° C. and coli-aerogenes organisms at the various sampling stations on the river.

TABLE No. 40.—*Comparison of the bacterial pollution of the Ohio River below Cincinnati, Ohio, during 1914–1916 and 1929–30*

Station	Winter period—open channel				Summer period—pool stage[1]			
	Average quantity units, 37° C. organisms		Average quantity units coli-aerogenes organisms		Average quantity units, 37° C. organisms		Average quantity units coli-aerogenes organisms	
	1914–1916	1929–30	1914–1916	1929–30	1914–1916	1929–30	1914–1916	1929–30
461	303, 100	307, 200	5, 330	10, 000	161, 500	36, 000	4, 600	130
Little Miami	44, 900	30, 800	320	710	25, 700	64, 500	290	790
Licking	49, 600	18, 200	720	470	42, 900	4, 000	1, 120	46
475	573, 200	1, 453, 300	25, 400	32, 890	3, 077, 400	1, 457, 500	86, 200	27, 560
482	673, 100	1, 362, 300	31, 100	26, 590	2, 359, 400	----------	57, 900	----------
486	958, 000	916, 500	18, 700	25, 030	2, 259, 100	940, 300	49, 600	6, 970
Great Miami	120, 000	106, 100	2, 410	2, 560	39, 100	20, 500	830	8
492	1, 065, 900	926, 400	28, 800	21, 470	2, 330, 200	660, 100	53, 000	16, 500
503	----------	1, 213, 300	----------	30, 260	----------	482, 900	----------	10, 400
535	----------	732, 400	----------	21, 340	----------	108, 000	----------	1, 870
543	822, 000	----------	21, 710	----------	1, 385, 300	----------	16, 100	----------
Kentucky	----------	----------	----------	----------	73, 000	4, 500	270	33
548	----------	----------	----------	----------	1, 456, 300	17, 100	16, 400	51
598	----------	----------	----------	----------	222, 700	15, 700	5, 200	210

[1] 1914–1916 summer period represents combination of both pool and open river conditions.

The winter periods of Table No. 40 are both representative of open-channel conditions in the river below Cincinnati with average stream flows at station 475 of 157,700 and 171,400 second-feet during the years 1914–1916 and 1929–30, respectively, resulting in comparable times of flow in the river from Cincinnati to the Kentucky River below which bacteriological data are not available in winter for comparison. The average summer period of the years 1914–1916 is representative of partial pool conditions in the river between Cincinnati and Louisville (pool above Dam No. 37, open river below to head of the pool formed by Dam No. 41), with an average stream flow past Cincinnati of 26,200 second-feet. The summer period of 1930 is representative of complete pool conditions in the river with Dams Nos. 37, 38, 39, and 41 in operation and stream flows at Cincinnati averaging only 11,900 second-feet.

Comparing first the past and present bacterial pollution of the Ohio River below Cincinnati in the winter period of unobstructed flow, Table No. 40 indicates but little difference in the average number of 37° C. organisms above Cincinnati during these two winter periods of similar stream flow and channel conditions. The Little Miami and Licking Rivers contributed somewhat smaller numbers of 37° C. bacteria during 1929–30 than in 1914–1916, but other sources of bacterial pollution within the metropolitan area resulted in larger numbers of these organisms in the river immediately below Cincinnati, at Stations 475 and 482, in the winter of 1929–30. Below Station 482 the number of 37° C. organisms in the main channel and those contributed by the Great Miami River were practically the same during both winter periods of observation. The data further indicate that in the winter period of open river conditions the number of coli-aerogenes organisms above Cincinnati during 1929–30 was nearly twice the number present during 1914–1916, but at all other points, as far downstream as the Kentucky River, the number of coli-aerogenes organisms in the river was practically the same in both periods of observation. In the winter period of unobstructed flow during the 1929–30 survey, the data indicate an increase in the number of 37° C. and coli-aerogenes organisms below the Great Miami River. While there were not as many sampling stations immediately below the Great Miami River during the 1914–1916 survey, these data at least suggest that a similar increase in bacteria may have been taking place in the river below the Great Miami at times of unobstructed flow.

In the summer period of the present survey, when all of the navigation dams were in operation and when stream flows from the watershed above Cincinnati approached the lowest ever recorded, the number of both 37° C. and coli-aerogenes organisms at every sampling station between Cincinnati and Louisville was much lower than at the same points during the 1914–1916 study. A slight increase in both 37° C. and coli-aerogenes organisms below the Great Miami River is suggested by the 1914–1916 data with pool stages throughout the river.

The indicated changes that have taken place in the Ohio River in the 15 years since the previous survey may, therefore, be summed up as follows: During the winter months of unobstructed flow in the river, when past and present conditions were entirely comparable, the bacterial load immediately below the lowest of the Cincinnati sewers was only slightly greater than in 1914–1916. During periods of open channel when times of flow are relatively short, a secondary increase in bacteria is indicated below the Great Miami River which may result in a bacterial load, nearly 30 miles below the sewers, almost as great as the load immediately below them. During the long period of pool stage which prevailed in the river in the summer of 1929–30, the average bacterial load in the Ohio River both above and below Cincinnati was very much less than during the summer period of 1914–1916.

Canalization and lower rates of stream discharge, giving longer times of flow, decreased velocities, and possibly permitting sedimentation, resulted in an improvement in the bacterial quality of the water entering the Cincinnati metropolitan area, also a smaller bacterial load in the river below the sources of pollution.

Conditions below Louisville.—In the section of the stream at Louisville, data are available during the present survey for the 13-month period, May, 1930 to May, 1931, inclusive. These data may be divided to represent three different sets of conditions in the stream through the metropolitan area; namely, a summer period of complete pool conditions represented by the months of May to November, 1930, inclusive, when the average stream flow was 13,900 second-feet and the estimated time of flow from the upper to the lower sampling station slightly in excess of 200 hours; a winter period of pool conditions represented by the months of December, 1930, January and February, 1931, with stream flows averaging 31,400 second-feet and times of flow between stations 598 and 624 approximately 70 hours, and a spring period of open channel represented by the months of March to May, 1931, inclusive, when the average stream flow was 144,000 second-feet and the time of flow between sampling stations approximately 13 hours.

At present the flow of the river past Louisville, between stations 598 and 605, is through the lower end of the pool formed by Dam No. 41 and then either in open channel or through the pool of Dam No. 43, between stations 605 and 624, depending upon the volume of stream flow. During the 1914–15 survey, the river flowed through the lower end of the pool above Dam No. 41, which was 8 feet lower than at present, and then always in open channel below the Louisville dam, since Dam No. 43 had not been constructed at that time.

The change in the location of the sampling stations at Louisville during the present investigation, in combination with the change in channel conditions, makes the comparison between the 1914–1916 and the 1930–31 data somewhat more difficult than in the upper section of the river. The results obtained from the earlier survey with sampling stations at Mile 611 and 619 indicated that during the summer period at least, the maximum effect of the sewage from the Louisville district may have been still farther downstream than the lower sampling point, since the average number of bacteria at station 619 was greater than the number at station 611. The lowest sampling station of the present survey was therefore located at mile 624 in an endeavor to determine conditions still farther downstream when the river below Dam No. 41 was flowing in open channel. Unfortunately the low stream flows of the summer, fall, and winter of 1930–31 made necessary the operation of Dam No. 43 and so lengthened times of flow below Louisville that the sampling station at mile 624 was probably considerably below the point of maximum bacterial pollution.

In the following tabulation (Table No. 41) there have been summarized, in terms of quantity units, the bacteriological data collected at sampling stations in the vicinity of Louisville during the 1930–31 investigation, divided into seasonal periods representing varying conditions of stream flow.

The 1930–31 results summarized in Table No. 41 indicate greater numbers of bacteria at station 598 as times of flow become less from upstream sources of pollution, and a general tendency for an increase in bacteria to take place between stations 598 and 605, a section of the stream receiving a portion of the sewage from the Louisville district. Between stations 605 and 624 the river receives the remaining sewage of the district, and an increase in bacteria is usually indicated when times of flow are relatively short; a decrease when velocities are lower and times of flow longest.

TABLE No. 41.—*Bacterial pollution of the Ohio River at Louisville in 1930–31, expressed as seasonal averages, in terms of quantity units*

Station	Summer (pool), May to November, 1930, inclusive		Winter (pool), December, 1930, January and February, 1931		Spring (open channel), March to May, 1931	
	37° C. organisms	Coli-aerogenes organisms	37° C. organisms	Coli-aerogenes organisms	37° C. organisms	Coli-aerogenes organisms
598	15,670	210	96,360	400	1,401,060	26,960
605	234,070	2,610	442,930	1,390	1,341,940	23,700
624	117,300	2,600	865,150	4,380	2,386,040	24,800

NOTE.—Estimated times of flow between stations 598 and 624: Summer 206 hours, winter 70 hours, spring 13 hours.

During winter and spring, with both pool and open-river conditions and with relatively short periods of flow, the effects of the sewage pollution from the Louisville metropolitan district are evident from the bacteriological findings at least, as far downstream as station 624, while in summer with increased times of flow past the sewers, the effects of sedimentation and natural processes of bacterial purification have a tendency to reduce the bacteria below station 605, offsetting to a considerable extent the effects of the sewage and wastes added below this station. The point of maximum bacterial pollution at pool stage in summer with decreased rates of run-off probably occurs in the vicinity of the lower sewer outlets, between Miles 605 and 611.

For the previous survey, data are available for the 14-month period, March, 1914, to April, 1915, at the three sampling stations maintained within the Louisville area at Miles 598, 611, and 619. Conditions in the river were essentially the same at all times during the earlier study, the river flowing through the pool of Dam No. 41, then in open channel through the remainder of the district. The bacteriological results during March, 1914, to April, 1915, at Louisville, expressed in terms of quantity units of bacteria, are summarized in Table No. 42.

The 1914–15 data indicate larger numbers of bacteria above the Louisville district (station 598), with shortened times of flow from upstream sources of pollution; an increase in bacteria (stations 598 to 611) between which all of the sewage of the Louisville area reached the river, and a still further increase in bacteria during the 8 mile flow below the sewers, suggesting that the effects of pollution in 1914–15 extended at least as far downstream as Mile 619. With unobstructed flow at all times below Dam No. 41, in 1914–15, the greatest numbers of bacteria, within and below the zone of pollution, occurred during the summer months, but at station 598, above the sources of pollution, the bacteria were somewhat higher during the winter period when times of flow from upstream sources of pollution were shortest.

TABLE No. 42.—*Bacterial pollution of the Ohio River at Louisville in 1914–15, expressed as seasonal averages in terms of quantity units*

Station	Summer (April to November)		Winter (December to March)	
	37° C. organisms	Coli-aerogenes organisms	37° C. organisms	Coli-aerogenes organisms
598	158,700	5,520	426,700	6,640
611	574,100	17,050	499,200	11,320
619	697,000	22,520	482,300	14,270

NOTE.—Estimated mean time of flow between stations 598 and 619: Summer 32 hours, winter 10 hours.

Comparing past and present conditions in the river at Louisville, the data of Tables Nos. 41 and 42 show that immediately above the city the least bacterial load occurred during the present survey at a time of minimum stream flow and maximum times of flow from Cincinnati. The greatest bacterial load also occurred, during the present survey, in the spring months of 1931, when velocities in the river began to increase following an 11-month period of pool stage combined with exceptionally low velocities. In this instance the movement of material deposited during low-water stages may have been a factor in the increased bacterial load within the Louisville area.

Considerably smaller numbers of both 37° C. and coli-aerogenes organisms were present above Louisville during pool stage in the winter of 1930–31 than in the winter of 1914–15, before all of the navigation dams were placed in operation. While the data at sampling stations within and below the metropolitan area are not entirely comparable, they suggest somewhat higher 37° C. and smaller numbers of coli-aerogenes organisms in the winter of the present survey, 1930–31, as compared with those present in 1914–15.

As already indicated, the number of bacteria present during pool stage of the summer of 1930 was much less than in the summer of 1914 with partial pool stage.

The following conclusions relative to present conditions in the Ohio River at Louisville and the effects of canalization appear to be justified.

The bacterial load below Louisville is apparently greatest at times of unobstructed flow following pool stages, and tends to be high during all periods of open-river conditions when times of flow are relatively short. During the 1929–1931 investigation the effects of pollution extended downstream at least 12 miles below the lowest sewer outlets. Sufficient data were not available to determine whether the increased 1930–31 bacterial load during open channel was due to increased pollution reaching the river or to the movement of material deposited during pool stage and flushed downstream with increasing velocities. With the extremely low flows of the summer and fall of 1930, during a period of continuous pool stage, the bacterial load throughout the whole Louisville area was much less than during 1914–1916.

Navigation dams decreased velocities and increased times of flow to such an extent that sedimentation and natural processes of stream purification took place within shorter distances along the river, resulting in an improvement in the water entering the area and shortening the distance below the city that bacterial pollution could be observed. At times of pool stage the maximum bacterial pollution undoubtedly occurs within the zone of pollution rather than at a point considerably below the sewers. As the pollutional load increases, greater numbers of bacteria will be observed at increasing distances downstream, especially at times of unobstructed flow following pool stage. Conditions in the Ohio River at Louisville during 1930–31 with unusually low stream flows were such that it seems reasonable to assume that during periods of normal stream discharge the river will care for considerably larger amounts of sewage and industrial wastes than are at present being discharged into it, without producing an excessive bacterial load either within or below the metropolitan area.

NATURAL PURIFICATION

The bacteriological findings indicate increases in the number of organisms as the Ohio River flows through the Cincinnati metropolitan area, which reach a maximum below the sewer outlets either at station 475, 482, or 488, depending to a considerable extent upon the time of flow in the river. After the maximum is reached, there is a marked tendency for the organisms to decrease, sometimes with fluctuations, as the distance increases below the sources of pollution at Cincinnati. With the addition of the sewage and wastes from the Louisville area, an increase is again indicated in the number of organisms present in the river. The bacteriological results in the vicinity of the Great Miami River suggest that under certain conditions the regular decrease in bacteria below the point of maximum concentration may be temporarily interrupted, the dilution by the tributary apparently affecting the biological balance of the stream to such an extent that a temporary increase in organisms is indicated in the section between stations 492 and 503.

BACTERIAL CHANGES IN 1929–30

In order that the indicated changes in the number of organisms in the river between Cincinnati and Louisville might be studied quantitatively, under the different conditions prevailing during the present investigation, the bacteriological and hydrometric data have been rearranged and assembled to show:

(*a*) Seasonal averages of 37° C. and coli-aerogenes organisms, in terms of quantity units, at successive sampling stations below station 475, with corrections [18] for tributary inflow below their points of confluence.

(*b*) Seasonal averages of quantity units of 37° C. and coli-aerogenes organisms, expressed as the percentage remaining at each sampling station below station 475.

(*c*) Seasonal averages of times of flow in the stream from station 475 to each successive sampling point below.

Two seasonal periods have been selected for comparison, open-river conditions, represented by the months of November, 1929, to April, 1930, inclusive, and pool conditions represented by the months of May to November, 1930, inclusive. This division of the data results in two periods for comparison, more strictly representative of open channel conditions in the winter and spring and pool-stage conditions of the summer and fall.

Table No. 43 summarizes, as seasonal averages, during these two periods, the quantity units of bacteria at each of the sampling stations below station 475, corrected for tributary inflow, and shows the percentage of the quantity units of bacteria remaining at each sampling station with reference to those at station 475, together with the average seasonal cumulative times of flow to the several points below station 475. Times of flow are based on the average of the individual monthly times.[19]

The data of Table No. 43 have been shown graphically on semilogarithmic cross-section paper in Diagram No. 5, with the percentages of bacteria remaining at successive stations below station 475 as ordinates and the times of flow as abscissae.

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[18] The bacteria added to the main stream by a tributary have been assumed to increase or decrease below the point of confluence in the same manner as the indicated changes taking place in the main channel bewеen sampling stations above and below the tributary. When a decrease in bacteria is indicated between two such stations, a similar rate of decrease has been assumed to occur in the bacteria added by the tributary. If increases in bacteria are indicated in the main stream past the tributary, a similar increase in the organisms contributed by the tributary has been assumed to take place. Such an assumption is the only justifiable one which offers a practical method of applying a correction to observations at successive sampling points.

[19] Average seasonal times of flow may be estimated from the mean seasonal discharge or as the average of the individual monthly times of flow. When stream flows are uniform during each month of the seasonal period, the mean time calculated by either method is essentially the same. One month of excessive run-off so affects the mean discharge that times of flow estimated from the average seasonal discharge may be considerably different from the average of the individual monthly times of flow. It is believed that the average of the individual monthly times of flow is more representative of actual conditions in the stream, and it has been used in estimating mean seasonal times of flow in these computations.

TABLE No. 43.—*Seasonal averages of quantity units of bacteria between Cincinnati and Louisville in 1929–30, corrected for tributary inflow and expressed as the percentage of those present at stations 475 with corresponding times of flow below station 475*

A. WINTER SEASON—OPEN CHANNEL

Station	37° C. organisms		Coli-aerogenes organisms		Mean time of flow, hours
	Seasonal average quantity units	Per cent remaining below station 475	Seasonal average quantity units	Per cent remaining below station 475	
475	1,485,280	100.0	32,890	100.0	0
482	1,362,300	91.8	26,540	80.7	2.1
488	918,460	61.8	25,680	78.0	5.5
492	835,290	56.3	18,910	57.5	7.6
508	1,075,000	72.4	26,640	81.0	12.5
525	648,900	43.7	18,860	57.3	28.3

B. SUMMER SEASON—POOL STAGE

Station	37° C. organisms		Coli-aerogenes organisms		Mean time of flow, hours
	Seasonal average quantity units	Per cent remaining below station 475	Seasonal average quantity units	Per cent remaining below station 475	
475	1,457,460	100.0	27,560	100.0	0
478	940,220	64.6	6,970	25.3	64
488	630,980	43.3	16,530	60.1	77
508	467,540	32.1	10,380	37.6	149
525	104,940	7.2	1,870	6.8	271
548	15,890	1.1	50	.2	283
598	14,580	1.0	206	.7	815

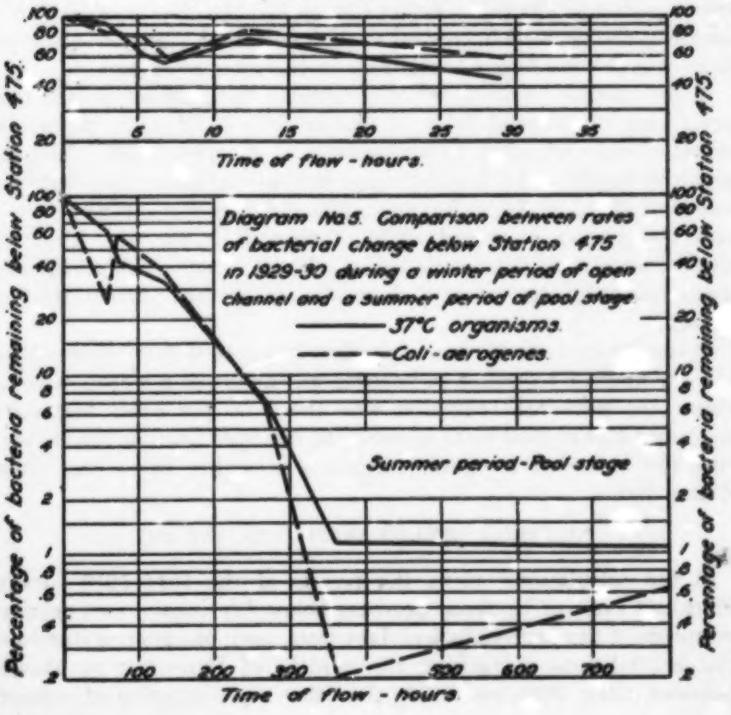


Diagram No.5. Comparison between rates of bacterial change below Station 475 in 1929-30 during a winter period of open channel and a summer period of pool stage.

For the winter period of open channel, data are available below Cincinnati only as far downstream as the Kentucky River. Table No. 43 and Diagram No. 5 indicate that in this winter period, with an average time of flow along the 60 miles between stations 475 and 535 of about 29 hours, the changes in both 37° C. and coli-aerogenes organisms were practically the same, the percentage decreases of 37° C. organisms being slightly greater than the corresponding reductions in coli-aerogenes organisms. During the first seven hours of flow between stations 475 and 492, there was a decrease in bacteria, followed by an increase which appears to have taken place during the 5½ hours' flow between stations 492 and 503. Below station 503 a continuation of the decrease in bacteria takes place.

During the summer period of pool stage, times of flow are materially increased, the average time between stations 475 and 535 being estimated at 271 hours and from station 475 to Louisville, station 598, about 814 hours. As in the case of the winter period, decreases in both the 37° C. and coli-aerogenes organisms are fairly consistent, a slight variation in the rates being indicated immediately below station 475, due to exceptionally low concentrations of coli-aerogenes organisms in the months of July and August, at station 488. However, with this exception the rates of decrease are fairly comparable over a period of 300 hours below station 475. In the lower section of the river, the bacteria decreased to such an extent that minor fluctuations caused considerable variations in the rates of change.

In the summer period, with long times of flow, the increase in bacteria, such as occurred below the Great Miami River in the winter period of open channel, is not apparent. In winter the initial decrease in bacteria and the indicated increase all took place within a period of about 12 hours below station 475. In the summer period, with the greatly increased times of flow, it is probable that the actual fluctuations in bacteria taking place are not indicated because of the relatively long times of flow between the sampling stations as located.

In the summer period, during the first 30 hours of flow below station 475, the average reduction in bacteria was about 35 per cent, while in winter the indicated reduction was about 50 per cent, suggesting somewhat higher final rates of bacterial disappearance in winter even with the indicated temporary increase occurring below the Great Miami River.

BACTERIAL CHANGES IN 1914, 1915, AND 1916

In the calculations, using the results of the 1914–1916 survey, indicating rates of bacterial decrease below Cincinnati, two primary groupings of the bacteriological data were used, one representative of winter conditions comprising the months of December to March, inclusive, 1914, 1915, and 1916; the other representative of summer conditions as indicated by the months of April to November, inclusive, during the same three years. In these earlier calculations, rates of bacterial decrease were estimated below points of maximum bacterial pollution, the derived curves indicating an average rate of bacterial disappearance below a number of different points at which the greatest concentration of bacteria was observed during the different months comprising the seasonal period. This method of calculation was justified on the assumption that after once reaching a maximum, the bacteria, in the absence of additional pollution, would decrease at constantly diminishing rates below the point of highest pollution. In a number of months the point of maximum concentration occurred at considerable distances below the sewer outlets and in some cases after an initial decrease in bacteria had taken place. In these instances the lower numbers of bacteria occurring at stations above the maximum point were disregarded, the derived rates of decrease having a tendency to be somewhat greater than was actually the case.

If, as suggested by the data of the 1929–30 survey, collected from more sampling points below the Great Miami River, the inflow of the tributary disturbs in some manner the biological balance of the main stream, resulting in a temporary increase in bacteria below the point of confluence, it would appear more logical to refer changes in organisms to a fixed reference point below the sewers, preferably at the place where the initial normal increase in bacteria below the outlets stops.

In the following comparisons between the 1914–1916 and the 1929–1930 data, the changes, in bacteria during 1914–1916 have been recalculated to show in all instances fluctuations below station 475 rather than decreases below the point of maximum pollution. The original 1914–1916 curve of winter bacterial decrease was based on the mean of the 12-month observation, December to March, inclusive, for the three years of the survey. These months represent open river conditions with the navigation dam below Cincinnati down, giving conditions entirely comparable to the months of November, 1929, to April, 1930, inclusive, of the present investigation, also representing open river conditions in winter. The data for the original summer curve were based on a 24-month period, April to November, inclusive, 1914, 1915, and 1916, which included 12 months, not consecutive however, in which Dam 37, below Cincinnati, was in operation, forming a pool within the Cincinnati area, and 12 months during which the dam was down and the river flowed in open channel past the city.

In addition to changing the point below which comparisons of rates of bacterial fluctuations have been calculated, from the point of maximum pollution to station 475, the 1914–1916 data have been further divided to indicate differences in the summer rates of bacterial change below Cincinnati when Dam 37 was and was not in operation.

In the following tabluation (Table No. 44) there are presented the recalculated 1914–1916 data showing the bacterial changes below station 475 during a winter period of open channel, a summer period when Dam 37 was down and the river flowing unobstructed past Cincinnati, and a summer period when Dam 37 was raised, forming a pool within the Cincinnati area. The data are summarized as the average number of quantity units of bacteria at each sampling station, as the percentage of bacteria remaining at each point below and with reference to those at station 475, and as the mean time of flow from station 475 to successive points on the river below.

TABLE No. 44.—*Seasonal averages of quantity units of bacteria between Cincinnati and Louisville in 1914–1916, corrected for tributary inflow and expressed as the percentage of those present at station 475 with corresponding times of flow below station 475*

A. WINTER SEASON—OPEN CHANNEL

Station	37° C. organisms		Coli-aerogenes organisms		Mean time of flow, hours
	Seasonal average quantity units	Per cent remaining below station 475	Seasonal average quantity units	Per cent remaining below station 475	
475	873,180	100.0	35,380	100.0	0
[illegible]	673,100	77.1	21,070	59.4	3.2
[illegible]	968,010	110.0	18,700	52.9	5.6
[illegible]	945,920	108.0	26,490	74.6	7.1
543	731,000	83.7	19,900	56.2	27.7
[illegible]	622,500	71.3	11,580	32.7	54.3

B. SUMMER PERIOD—DAM 37 RAISED

Station	37° C. organisms		Coli-aerogenes organisms		Mean time of flow, hours
	Seasonal average quantity units	Per cent remaining below station 475	Seasonal average quantity units	Per cent remaining below station 475	
475	3,513,010	100.0	96,580	100.0	0
[illegible]	2,234,900	63.6	47,890	49.7	12.4
[illegible]	1,579,410	44.9	36,820	38.2	18.2
[illegible]	1,497,840	42.7	35,310	36.6	21.4
543	584,000	16.6	7,140	7.4	73.9
[illegible]	72,000	2.0	1,310	1.3	184.3

C. SUMMER PERIOD—DAM 37 LOWERED

Station	37° C. organisms		Coli-aerogenes organisms		Mean time of flow, hours
	Seasonal average quantity units	Per cent remaining below station 475	Seasonal average quantity units	Per cent remaining below station 475	
475	2,641,870	100.0	75,740	100.0	0
[illegible]	2,482,980	94.0	67,920	89.7	4.2
[illegible]	2,930,720	111.0	62,300	82.3	7.2
[illegible]	3,064,220	116.0	68,980	91.1	9.1
543	2,405,060	91.1	27,560	36.4	35.7
[illegible]	342,050	12.9	8,800	11.6	78.3

The data of Table No. 44 are shown graphically on Diagram No. 6 which includes also, for comparison, the original rates of decrease in 37° C. and coli-aerogenes organisms, below the point of maximum concentration during a winter and summer season, irrespective of the operation of Dam 37 below Cincinnati.

In each instance, in Diagram No. 6, the recalculated bacterial changes below station 475 show rates of decrease lower than the rates indicated below the point of maximum concentration, due as already intimated to the utilization of all data at each station when determining changes below station 475 and omitting the data at stations above the point of greatest bacterial concentration in calculating changes below the point of highest pollution. The three groups of curves are consistent in that the rates of change of coli-aerogenes organisms are in each instance greater than the rates of change in the 37° C. organisms.

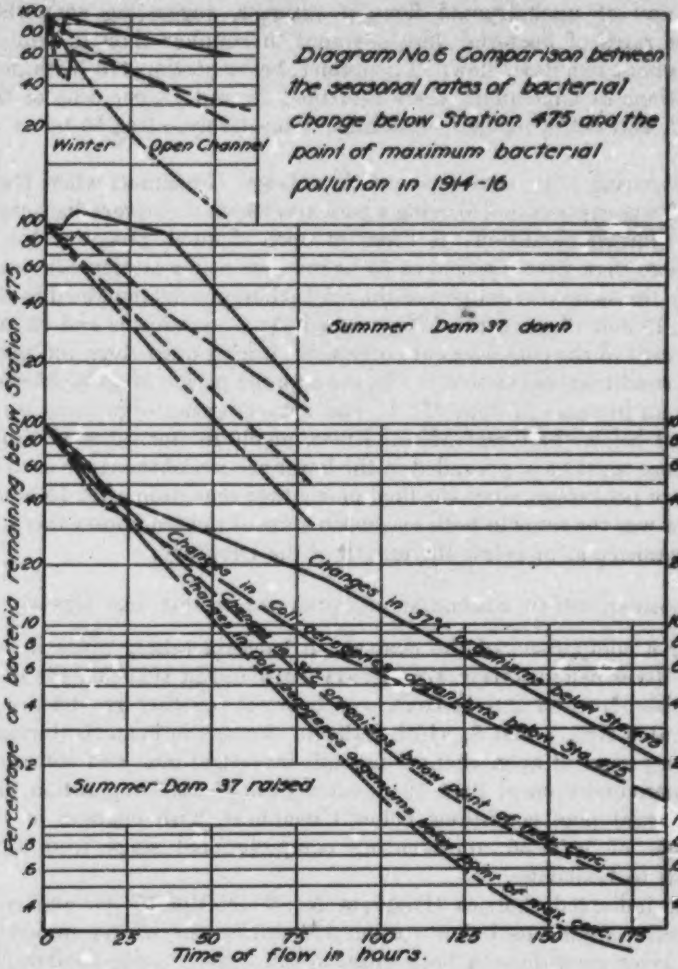


Diagram No. 6 Comparison between the seasonal rates of bacterial change below Station 475 and the point of maximum bacterial pollution in 1914-16

Fluctuations in the number of bacteria apparently occur during a period of about 10 hours' flow between station 475 and the Great Miami River in both the summer and winter periods of unobstructed flow in the river channel. With the navigation dam below Cincinnati raised, forming a pool and increasing times of flow in the upper section of the stream, no such fluctuations are indicated, a consistent decrease in bacteria taking place below the zone of pollution.

Comparing open river conditions in summer and winter, the data show that 72 and 35 per cent of the 37° C. and coli-aerogenes organisms, respectively, remained in the water after a period of 50 hours' flow in winter, while 45 and 25 per cent, respectively, remained after 50 hours of unobstructed flow in summer, suggesting somewhat higher rates of bacterial disappearance in summer than in winter, after about two days' flow. In summer, below station 475, with pool conditions at Cincinnati, there remained 23 and 18 per cent of the 37° C. and coli-aerogenes organisms, respectively, after 50 hours of flow.

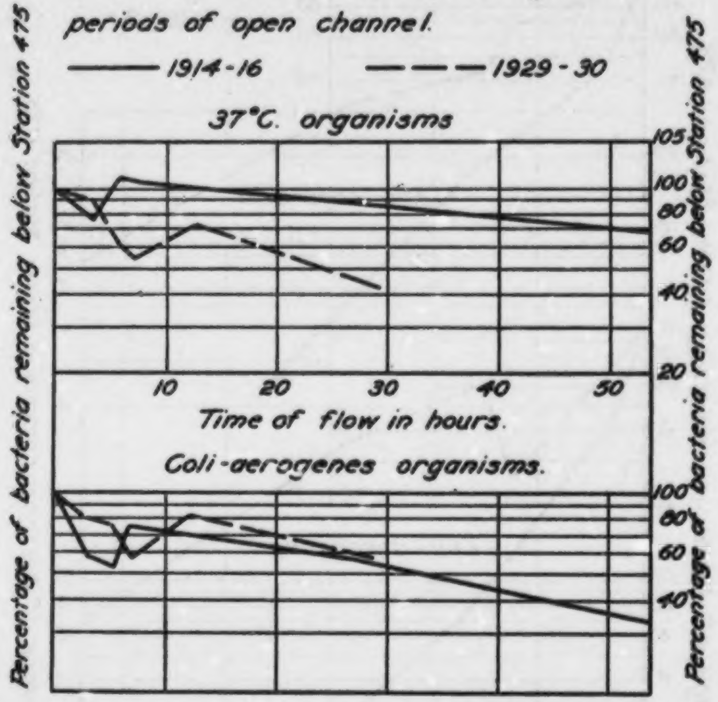
Comparing next, summer conditions below Cincinnati when Dam No. 37 was in operation forming a pool into which the sewers discharge, with summer conditions at times of open channel, Diagram No. 6 indicates that after a period of 75 hours' flow below station 475 practically the same percentages of the original organisms remained in the river; 15 and 19 per cent of the original 37° C. organisms and 12 and 9 per cent of the coli-aerogenes organisms during open-river and pool-stage conditions respectively. In the summer period of open channel, when an increase in both 37° C. and coli-aerogenes organisms is indicated below the Great Miami River, much greater rates of disappearance must have prevailed in the lower section of the river than at times of pool stage, since the final percentage reduction after 75 hours of flow was the same in both seasons in spite of the temporary increase in organisms at or below the mouth of the tributary.

COMPARISON OF BACTERIAL CHANGES IN 1914–1916 AND 1929–30

For a comparison of the changes in bacteria taking place in the Ohio River below station 475 in 1914–1916 and in 1929–30, the data of Tables Nos. 43 and 44 have been brought together graphically in Diagrams Nos. 7 and 8, which indicate changes in bacteria during a winter period of open channel in both investigations, and compares summer conditions of 1914–1916, when Dam 37 was in operation, giving partial pool conditions below Cincinnati, with changes in the summer of 1929–30, representing complete pool stage from Cincinnati to Louisville.

The indicated changes (Diagram No. 7) in the 37° C. and coli-aerogenes organisms below station 475 during the winter period of open river conditions in both years are in general quite similar, the data suggesting first a decrease in bacteria below the Cincinnati sewers, which continues to the vicinity of the Great Miami River, an increase starting below the tributary and continuing for varying distances downstream, followed by a secondary decrease in bacteria which lasts until Louisville is reached. The 1929–30 rates of decrease in 37° C. organisms appear to be somewhat greater than the 1914–1916 rates, but the changes in coli-aerogenes organisms in 1929–30 were somewhat smaller than those of 1914–1916. In the 1929–30 winter period the average stream discharge was 158,000 second-feet, the concentration of 37° C. and coli-aerogenes organisms, at station 475, 7,000 and 280 per cubic centimeter, respectively. In the winter period 1914–1916, stream flows averaged 160,000 second-feet, and the

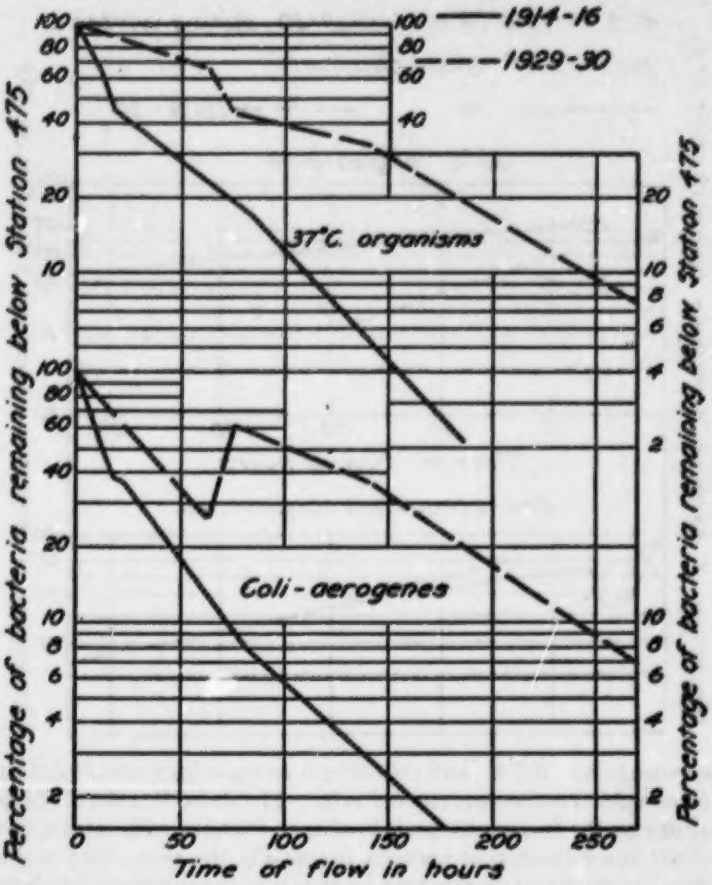
Diagram No. 7 Comparison between the rates of bacterial change below Station 475 in 1914-16 and 1929-30, during winter periods of open channel.



concentration of 37° C. and coli-aerogenes organisms was 10,300 and 210 per cubic centimeter, respectively. The data, therefore, suggest that during the two winter periods of open channel, with stream flows and the concentration of bacteria practically the same, very similar changes in the bacteria occurred in the Ohio River below Cincinnati.

In the two summer periods of pool conditions (Diagram No. 8) marked variations apparently occurred in the rates of bacterial change below Cincinnati, the 1929–30 rates being very much less than the rates in 1914–1916. Pool stage in 1914–1916 was confined to the river above Dam 37, the river flowing in open channel below the dam to the head of the pool formed by Dam 41 at Louisville, a distance of about 50 miles. In 1929–30 pool conditions existed throughout the section of the river between Cincinnati and Louisville, the river flowing successively through the pools formed by Dams 37, 38, 39, and 41. No increases in bacteria are indicated in the vicinity of the Great Miami River in summer with pool conditions, although a slowing up in the rate of decrease is indicated by the 1914–1916 results between

Diagram No. 8 Comparison between the rates of bacterial change below Station 475 in 1914-16 and 1929-30, during summer periods of pool stage.



stations 488 and 492. The apparent increase in coli-aerogenes organisms in 1929–30 between stations 488 and 492 is accounted for by exceptionally low concentrations of these organisms in two of the months comprising the seasonal average. The 1929–30 average summer stream discharge was 11,900, that of the summer of 1914–1916 about 26,200 second-feet. Due to decreased run-off in the summer and fall of 1929–30, the actual numbers of 37° C. and coli-aerogenes organisms present in the river at station 475, during the later survey, were 41 and 29 per cent respectively of those present at the same point in 1914–1916. The mean time of flow through the metropolitan district in 1929–30 (station 461 to 475) was about 57 hours, and only 17 hours in 1914–1916. Increased times of flow in 1929–30 undoubtedly permitted more extensive sedimentation than in 1914–1916, and acted in conjunction with the natural agencies of stream purification to reduce the actual numbers of bacteria present in the river below the sewers. Comparing summer open river conditions, 1914–1916, summer partial pool conditions, 1914–1916, and complete pool conditions, 1929–30, the data indicate smaller initial numbers of bacteria below the sewer outlets and decreasing rates of bacterial disappearance as times of flow increase through and below the zone of sewage pollution.

Variations in the initial number of organisms present, however, do not appear to account wholly for the variation in rates of bacterial disappearance with changes in river conditions, the effect of mechanical removal by sedimentation or changes in the condition or types of organisms, after long periods of flow at pool stage, may be factors influencing rates of decrease under such conditions.

BACTERIAL POLLUTION BELOW CINCINNATI IN 1929–30, ESTIMATED FROM THE 1914–1916 RESULTS, COMPARED WITH THE OBSERVED POLLUTION IN 1929–30

In the following calculation, a comparison has been made between the actual numbers of quantity units of bacteria present in the river below Cincinnati during 1929–30 and the estimated number present in 1929–30, calculated from the indicated rates in 1914–1916 below the point of maximum concentration.

Quantity units of bacteria immediately below the Cincinnati metropolitan area have been estimated from the 1914–1916 per capita contributions of 37° C. and coli-aerogenes organisms [30] and the 1930 estimates of sewered population in the district.

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[30] In Tables Nos. 161 and 162, p. 265, Public Health Bulletin No. 143, A Study of the Pollution and Natural Purification of the Ohio River, seasonal increases in the bacterial pollution of the Ohio River in its passage past Cincinnati are shown, from which the following seasonal averages of per capita contributions of bacteria have been calculated: Winter period, December to March, inclusive, 1.04 and 0.057 quantity units per capita per day of 37° C. and coli-aerogenes organisms, respectively; summer period, April to November, inclusive, 7.09 and 0.191 quantity units per capita per day of 37° C. and coli-aerogenes organisms, respectively.

The theoretical number of bacteria remaining at sampling stations below Cincinnati in 1929–30 has been estimated from the concentration below the sewers, by using the 1929–30 mean seasonal times of flow with the 1914–1916 rates of bacterial decrease. In Table No. 45 the estimated quantity units of bacteria have been compared with those actually observed in the river at the various sampling points between Cincinnati and Louisville during the 1929–30 investigation.

TABLE No. 45.—*Comparison between the calculated and observed seasonal quantity units of bacteria in the Ohio River below Cincinnati during 1929–30*

Station	Winter—open channel				Summer—pool stage			
	Quantity units of 37° C. organisms		Quantity units of Coli-aerogenes		Quantity units of 37° C. organisms		Quantity units of Coli-aerogenes	
	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed
475	925,000	1,452,000	24,300	22,900	4,207,000	1,457,000	115,000	37,000
482	575,000	1,262,000	28,400	28,600	----------	----------	----------	----------
488	560,000	918,000	25,400	25,000	388,000	940,000	6,900	7,000
492	532,000	822,000	22,300	18,900	226,000	640,000	4,000	16,300
508	475,000	1,075,000	17,900	26,900	26,000	408,000	470	10,400
535	269,000	649,000	8,600	18,800	7,050	106,000	120	1,900
548	----------	----------	----------	----------	3,400	16,000	75	80
596	----------	----------	----------	----------	46	15,000	7	210

NOTE.—Observed results corrected for the inflow of the Great Miami and Kentucky Rivers.

Comparing first the winter period of open channel, the actual quantity units of 37° C. organisms present in the stream were from 1.5 to 2.4 times the estimated number. The estimated and actual quantity units of coli-aerogenes present in the river in winter agree quite closely between stations 475 and 492, but below the Great Miami River the secondary increase indicated by the 1929–30 data and not by the 1914–1916 results, shows the actual number of bacteria present to be considerably higher than the calculated number.

In the summer period of pool stage the estimated quantity units of 37° C. organisms immediately above the sewers exceeded those actually present; but at all other sampling stations the observed quantity units were in excess of the calculated number, from 2.4 to 3.2 times in the upper section and from 15 to 20 times in the middle section of the river. The calculated number of coli-aerogenes organisms in summer, immediately above the sewers, was greater than the observed number but, as in the case of the 37° C. organisms, the actual quantity units of coli-aerogenes organisms present at practically all other points exceeded the calculated number from 1.3 to 27 times.

It would seem probable, in the light of the variation between the 1914–1916 and 1929–30 rates of bacterial decrease under different conditions of stream flow, and by the differences in calculated and actual numbers of bacteria present in the stream, that quite substantial errors might arise by attempting to estimate the present bacterial pollution in the Ohio River below Cincinnati, by applying the indicated 1914–1916 rates of decrease below the zone of maximum pollution.

Changes in the amount and character of the sewage and industrial waste pollution within the Cincinnati metropolitan area have undoubtedly taken place since the previous investigation. Times of flow have been greatly increased at pool stages as a result of complete canalization since the previous study and sedimentation or changes in the character and types of organisms present in the river after protracted periods of flow may have materially changed rates of bacterial decrease from those of the past. Tributary inflow, by dilution or some other undetermined cause, appears to produce, at times, temporary increases in bacteria in the river below the confluence, suggesting fluctuations in bacteria rather than a uniform decrease below the zone of pollution. Considerable error in the number of organisms present in the middle section of the stream below the entrance of tributaries at times of unobstructed flow may be introduced by the application of uniform rates of bacterial decrease below the point of maximum concentration.

SECTION VII

GENERAL SUMMARY

Conditions affecting the sanitary condition of the Ohio River between Cincinnati and Louisville since the 1914–1916 survey have resulted from:

The construction of Dams Nos. 38 and 39 between the two cities and the increased elevation (8 feet) of Dam No. 41 at Louisville.

An increase in total population on the watershed above Cincinnati of 1,226,900, of which increase 1,059,900, or 86 per cent, is urban and 167,000, or 14 per cent, is rural.

Increase in population on the watershed between Cincinnati and Louisville totaling 432,800, of which 381,500, or 88 per cent, is urban and 51,300 or 12 per cent, is rural.

An increase in sewered population on the watershed above Cincinnati, estimated at approximately 867,000.

Increases in sewered population at Cincinnati (106,000), at Louisville (105,200), and between the two cities (1,300), making a total of approximately 889,000 persons contributing sewage directly to the section of the river under observation, 601,000 at Cincinnati, 285,000 at Louisville, and 3,000 between the two cities.

Studies of the precision of the oxygen determinations, as a measure of the effect of pollution, suggest:

That to be of significance, changes in the amount of dissolved oxygen, and oxygen demand, between successive points, should be in excess of about ± 10 and ± 30 per cent, respectively.

That with stream flows of 50,000 second-feet or more, the pollution from the Cincinnati metropolitan area is not sufficient to produce significant changes in the dissolved oxygen and oxygen demand and the determinations, under such conditions, are not of value in determining the effects of pollution.

That when stream flows are 50,000 second-feet or less, the sewage from the Cincinnati metropolitan area causes marked changes in the oxygen determinations, increasing the oxygen demand and reducing the dissolved oxygen in amounts increasing in significance as the stream flows diminish. Under normal conditions of stream discharge (unobstructed flow), the oxygen determinations become of considerable value in measuring the effects of pollution.

That at times of low velocities permitting the sedimentation of sewage materials and reducing the oxygen demand below the sources of pollution, the effects of sewage and wastes tend to be underestimated; while at times of increasing velocities, following pool conditions, the scour of previously deposited material may result in overestimating the effects of pollution.

Changes in the sanitary condition of the Ohio River, between Cincinnati and Louisville during the past 15 years, have been studied by comparing 1914–1916 and 1929–1931 seasonal averages; consisting of winter periods, representing open-river conditions when stream flows and other conditions were essentially the same during both periods of investigation; and summer periods, representative of partial pool conditions in 1914–1916 and complete pool conditions in 1929–1931, when stream flows averaged about 20 per cent of those in 1914–1916.

Comparisons of the oxygen relationships during these seasonal periods of 1914–1916 and 1929–1931 indicate:

But little change in sanitary conditions during the past 15 years at times when the river flows unobstructed by the navigation dams. In the winter of 1930 the amount of dissolved oxygen carried by the river was slightly greater than in 1914–1916, the amount of oxygen demand approximately one-half that of 1914–1916, resulting in a larger oxygen reserve at the present time than in the past.

That in the summer period of 1929–1931, with pool stages throughout the river and stream flows a minimum, the amount of dissolved oxygen was from 70 to 80 per cent and the oxygen demand from 60 to 70 per cent of that of 1914–1916, resulting in oxygen reserves of practically the same amount during both investigations.

That in August, 1930, with minimum mean monthly stream flows (3,360 second-feet), the dissolved oxygen below Cincinnati was completely exhausted, suggesting that critical oxygen conditions may have prevailed in the pool through the city, due to the sewage and sludge accumulated during the previous three months of pool stage.

Canalization and decreased rates of run-off permit sewage solids to settle near the sewer outlets, and result in the production of critical oxygen conditions near the points of pollution rather than at points further downstream where nuisances usually occur.

The bacteriological observations during these two periods of investigation indicate:

But slight differences in bacterial pollution of the river at times of unobstructed flow during the two surveys.

That with all navigation dams in operation and stream flows below normal, the bacterial load below Cincinnati during the summer of 1930 was much less than in the summer of 1914–1916.

That in the winter of 1929–30 the per capita contribution of 37° C. organisms from the Cincinnati metropolitan area was greater and the per capita contribution of coli-aerogenes organisms less than in 1914–1916.

That in the summer of 1930, with decreased velocities, and sedimentation probably taking place, the per capita contribution of bacteria was much less than the contribution in the summer periods of 1914–1916.

That at the Cincinnati and Louisville waterworks intakes the bacterial content of the raw water was such that the rather highly elaborated treatment processes at these two plants, combined with efficient operation and control, should be able with but little difficulty to produce for a large part of the time an effluent conforming to the Treasury Department standard.

That the indicated bacterial load of the raw water at plants within or immediately below the zones of pollution at Cincinnati and Louisville is such that less highly elaborated and less efficiently controlled and operated plants may have considerable difficulty for a large part of the time in producing effluents meeting the Treasury Department standard.

Canalization, permitting sedimentation and allowing longer times of flow between points in which natural purification agencies may operate, appears to have decreased the bacterial load in the river both above and below the Cincinnati and Louisville metropolitan areas during the summer and fall months when the navigation dams are usually in operation.

Comparison of the rates of bacterial change below the Cincinnati sewers in 1929–30, expressed as the percentage of organisms remaining at downstream points, in respect to time of flow, indicates:

Very similar mean rates of bacterial change in both the summer and winter periods.

That in winter, with higher rates of discharge and shorter times of flow, an increase in organisms takes place below the confluence of the Great Miami River, following an initial decrease below the zone of pollution.

That in summer, with increased times of flow, there is no secondary increase in bacteria below the confluence of the Great Miami River.

That in summer, after 30 hours' flow below the zone of pollution, about 65 per cent of the 37° C. organisms remained in the stream, while in winter about 50 per cent remained after the same period of flow.

The 1914–1916 bacterial results, recalculated to show changes below the zone of pollution rather than below the point of maximum bacterial concentration, indicate:

Rates of bacterial decrease below the zone of pollution less than the rates below the point of maximum bacterial concentration.

Fluctuations in bacteria at times of unobstructed flow very similar to the fluctuations observed in 1929–30 when channel conditions were comparable.

No increase in organisms below the Great Miami River when Dam No. 37 was in operation, increasing times of flow through the zone of pollution.

Comparison of the rates of bacterial change under different channel conditions during the two studies suggests:

Rates of disappearance of 37° C. organisms less than the rates of disappearance of coli-aerogenes organisms.

That decreasing velocities in the river tend to lower the concentration of bacteria immediately below the zone of pollution.

That as the initial concentration below the zone of pollution becomes less, the rates of bacterial decrease further downstream tend to diminish.

That variations in the initial concentration of organisms, however, do not appear to account entirely for the differences in bacterial disappearance and the mechanical removal by sedimentation, changes in the condition of the organisms present after long periods of flow, differences in the types of organisms present at pool stage, or the presence of other microscopic organisms or plants, may be factors influencing rates of change under such conditions.

That rates of bacterial decrease may not be uniform below a given point, because of fluctuations resulting from disturbances in biological balance due to tributary inflow or some other undetermined cause.

Considering the very different conditions existing in the channel between Cincinnati and Louisville during the present survey as compared with conditions at the time of past study—that is, complete canalization, exceedingly low stream discharge, resulting in greatly increased times of flow and possibly sedimentation behind the dams, which in turn affected the oxygen relationships and rates of bacterial change—it does not appear probable that an intelligent forecast of conditions, such as existed in the Ohio River during the summer of 1930, could have been made from the oxygen relationships and bacteriological findings obtained during the 1914–1916 investigation.

While canalization has a tendency to decrease the bacterial load in the stream, improve the bacterial quality of the water entering the metropolitan areas, and shorten the distance downstream that the effects of pollution can be observed, it also has a tendency to move the point of probable nuisance, due to oxygen depletion and anaerobic conditions, from points downstream to within the zone of pollution in the vicinity of the sewer outlets, where sludge banks form as a result of decreased velocities in the pools.

While decreased bacterial loads at the water works filtration plants make the production of an effluent of satisfactory bacterial quality less difficult, the effects of low turbidities in the river and increased numbers of microscopic organisms, with their tendency toward odor and taste production and shortened filter runs, more than offset the good effects of decreased bacterial loadings.

In addition, the concentration of decomposition products in the water from the fermentation of deposits of organic materials within the pools when the dams are in continuous operation, may have public health aspects heretofore not appreciated. Reference is made to the suspected water-bourne outbreak of gastroenteritis along the Ohio River at the time of and following the low-water conditions in the fall and winter of 1930–31.

Canalization, at least between Cincinnati and Louisville, has had a tendency to complicate rather than simplify the problems connected with sewage disposal, possible nuisance production, the operation of water-treatment devices, and the preservation of the public health.

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